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BULLETIN No. 171 DECEMBER, 1916

MASSACHUSETTS
AGRICULTURAL EXPERIMENT STATION

A CHEMICAL STUDY OF THE ASPARAGUS PLANT

By F. W. MORSE

This bulletin is the report of an investigation of the chemical composition of the asparagus plant and the effect of different fertilizers upon the proportions of the more important plant constituents. Its object is to supply more knowledge for the efficient culture of asparagus.

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Publication of this Document
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BULLETIN No. 171.

DEPARTMENT OF CHEMISTRY.

A CHEMICAL STUDY OF THE ASPARAGUS PLANT.

BY F. W. MORSE.[1]

INTRODUCTION.

The chemical composition of the asparagus plant (*asparagus officinalis*) has been under investigation in this laboratory for several years. The studies were begun in connection with a series of fertilizer experiments which have been conducted at Concord, Mass., where asparagus culture is an important industry.

The chemical composition of the asparagus plant has heretofore received comparatively little attention. Rousseaux and Brioux,[2] in a study of commercial asparagus culture in France, include numerous determinations of the inorganic constituents. Tanret[3] has investigated the soluble carbohydrates, or sugars. Wichers and Tollens[4] have reported the composition of the roots and crowns at different seasons. A few scattered analyses of the edible stalks have been found in different publications.[5]

Our studies have included several stages in the development of the asparagus plant, and also the effects produced by different methods of fertilization.

CROWNS AND ROOTS.

The first lot of material collected for the investigation consisted of crowns and roots taken from the experiment field at Concord early in November, 1908. One-year-old plants had been set in this field in the spring of 1907; therefore the roots when sampled were two and one-half years from the seed.

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[1] The author's indebtedness to Director Wm. P. Brooks and Dr. J. B. Lindsey for important suggestions regarding the work is gratefully acknowledged.

[2] Rousseaux and Brioux: Ann. Sciences Agron., 3d Series, I. (1906), pp. 188–326.

[3] Tanret: Bull. Soc. Chim. (4) 5, p. 889 (1909).

[4] Wichers and Tollens: Journ. fur Landwirthsch., 1910, p. 113.

[5] N. Y. Agr. Expt. Sta. Bull. 265; Office Expt. Sta. Bull. 28, p. 37.

The material was collected at this time for the purpose of determining the influences of the different fertilizers on the proportion of the reserve plant foods stored in the roots. The first crop of stalks would be cut from the plots in the following spring, and it was desirable to ascertain if any relationship could be demonstrated between the reserve food stored in the roots and the amount of growth made in the spring.

At the time the roots were dug the tops of the plants had been killed by frost and the stems were breaking down. It was consequently assumed that the roots had stored all the reserves of plant food which the stalks would have for their growth in the following spring.

Since these samples were primarily for studying the effects of fertilizers, each plot was represented by four plants which were selected by the size and number of their stalks, on the assumption that a plant with an average amount of tops would possess an average lot of roots.

The crown and attached roots of each plant were dug with spade and trowel by means of which the longest roots were followed to their tips. The word "roots" is used here to designate the rod-like storage roots of the plant, and not the fibrous feeding roots which were rubbed off during the washing process.

The roots in this lot were selected and the digging supervised by Mr. E. F. Gaskill, assistant agriculturist. The subsequent preparation of the samples for chemical analysis was supervised by Mr. P. H. Smith, in charge of the feed and dairy section of this department. The writer was assigned to this investigation in January, 1910, and the work has since been wholly in his charge.

A second lot of roots was collected on Nov. 4, 1910, by the writer and Mr. Gaskill after the plants had been set in the field three and one-half years. Two crops of stalks had been cut for market during their life, — a short crop in 1909 and a full crop in 1910. Plants were selected as before by the size and number of the matured stalks, which were in the same condition of decay as in 1908.

The roots had now ramified to such an extent that those of adjacent plants were more or less intermingled, making it impracticable to follow all roots of selected plants to their tips. Therefore a circle with a radius extending halfway to the adjacent plants in the row was cut with a spade around the chosen plant, after which the crown and attached storage roots were removed from the soil. It was noted that most of the roots ended in the characteristic pointed tips without cut ends, and were therefore fully representative of the plant.

The roots were shaken free of soil, put in sacks and shipped to Amherst. Two days elapsed between the removal of the roots from the soil and their reception at the laboratory. Upon their arrival they were placed in a cool cellar used for vegetable storage.

Each crown was next separated into small sections in order to remove adhering soil, and the parts, together with the attached roots, were scrubbed with a stiff brush, after which they were rinsed in clean water.

The material was next spread on a large sheet of paper in a cool place until the surface was free of adhering moisture. Each individual crown and its accompanying roots were then weighed and the weight noted down for the subsequent calculations as the fresh or green weight from the field.

The first stage of preparation of the material for analysis was to pass a sample, consisting of one crown and its corresponding roots, through a hand-lever feed-cutter, by which they were cut to lengths of about 1 inch (2.5 centimeters). The sample was then placed in a large steam-heated drying oven, where the temperature was about 55° C., and dried until sufficiently brittle to be easily pulverized.

In pulverizing asparagus roots for analysis certain properties of their constituents made serious trouble. During the preparation of the first lot of roots in 1908 Mr. Smith found the dried material to be so hygroscopic that in damp weather it would quickly become sticky and gum the mill. The friction of grinding was also apt to produce sufficient heat to make the material sticky and hopelessly cement the grinding plates together. By using a ball mill in dry weather he finally succeeded in reducing the samples to powder.

The writer's procedure with the samples of 1910 was as follows: immediately after removing the dried sample from the oven the material was allowed to cool a short time in the air and then weighed. Directly after weighing the sample was passed through a large drug mill, by which it was reduced to a mixture of coarse fiber and fine powder, the fiber coming from the outer walls of the roots and the powder from the interior and the crown. The mixture was subsampled by two successive quarterings.

The subsample was next sifted by means of a millimeter sieve, which separated nearly all of the fine powder from the fibrous shreds. By this step the hygroscopic, gummy constituent was largely eliminated from subsequent milling and the coarse fiber was pulverized about as readily as wheat bran, until it also passed through the millimeter sieve. The entire material of the subsample was thoroughly mixed and preserved in a tightly corked bottle for analysis. Care was taken to conduct all the operations in a dry atmosphere.

On June 23, 1911, at the end of the cutting season, a third lot of samples was taken for the purpose of determining the amount of exhaustion which the reserve material in the roots had undergone in producing the crop recently harvested. This lot of roots was collected under the supervision of Mr. C. W. Prescott, who was in charge of the Concord experiment field. There was practically no top growth by which to judge the size of a crown, and the roots were therefore necessarily chosen more at random than in the previous cases. On arrival of the roots at the laboratory they were treated in the manner described for the samples of 1910.

The average fresh weight of forty-four roots gathered from eleven different plots was found to be for each of two years, as follows: 1908, 1,092 grams; 1910, 2,440 grams. In two years the crowns and roots had more than doubled in size and weight.

The average weight of sixteen roots from four plots in each of three years is as follows: 1908, 1,120 grams; 1910, 2,393 grams; 1911, 2,401 grams.

The roots obtained in 1911 actually averaged slightly heavier than those selected the fall before. This may in part be due to the more random choice of samples in the summer before there was sufficient top growth to guide the selection, but is more probably the result of a higher water content in the growing season, as will be seen in the table of composition.

It has already been mentioned that the first object in collecting the different series of roots was to ascertain the effects of different fertilizers on their composition, but it is deemed best to present first the average composition of the roots at different stages of development, and follow with the composition of other parts of the plant before taking up the specific influences of methods of fertilization.

In furtherance of the primary object of the investigation, forty-four crowns, representing eleven different plots, were collected in the fall of 1908; seventy-six from nineteen plots in the fall of 1910; and sixteen from four plots in the summer of 1911.

A complete analysis was not made of every sample. Nitrogen was determined in every individual sample of each year. Total sugar was determined in about two-thirds of the samples obtained in 1908, and in every sample of the lots of 1910 and 1911. Ash and ash constituents were determined in every sample of the lot of 1908, but only in composite samples representing the individual plots in the series of 1910 and 1911. Dry matter was determined in every sample of 1910 and 1911, but was not calculated in the samples of 1908 because the weights after the first drying were omitted. The other constituents — fiber, pentosans and fat — were determined in selected samples in each series, chosen from some with average percentages of nitrogen or sugars, and others with maximum or minimum proportions.

In compiling averages for each year from the numerous analyses of individual samples above mentioned there were included only those figures obtained on samples from plots receiving complete fertilizers in some form, and results from plots receiving no nitrogen, no potash or no phosphoric acid were omitted.

Composition of Asparagus Roots.

	November, 1908.	November, 1910.	June, 1911.
Dry matter,	–	21.10	18.62
Ash in dry matter,	6.56	6.89	8.93
Protein,	12.25	12.44	12.75
Fiber,	15.39	19.77	23.66
Fat,	.98	1.77	1.63
Nitrogen-free extract,	64.82	59.13	53.03
Sugar in dry matter,	39.98	31.52	23.20
Pentosans,	8.91	10.96	11.66
Lignin, etc.,	15.93	16.65	18.17
Total nitrogen,	1.96	1.99	2.04
Protein nitrogen,	1.19	1.05	1.30
Amino nitrogen,	.77	.94	.74

NOTE. — The analytical methods employed throughout this work were those of the Association of Official Agricultural Chemists in all essentials.

The comparison shown by the table is of great interest. As the roots increased in size from 1908 to 1910 there was not a marked change in all constituents. The slight increase in ash may have been due to increased absorption and storage, and in part caused by the impossibility of thoroughly removing the adhering soil in washing the roots. The nitrogen percentage was practically unchanged, showing that the roots demanded and received that element as fast as new growth developed. There was a change in the relative proportions of the non-nitrogenous materials. In the soluble and active form the sugar was much less in the older roots, while the different inactive forms had all increased (fiber, pentosans, lignin and fat). There was a small change in the porportion of protein and amino nitrogen, which may have been a seasonal difference.

The sixteen random roots selected in 1911 from four plots, as already shown, weighed a trifle more than the roots gathered the fall before from the same plots. The analyses showed, however, a lower percentage of dry matter and actually lower weight on that basis. There was a pronounced exhaustion of sugars in the spring growth, but none of the other constituents; instead, the other constituents were increased in proportion to the loss of sugars. Nitrogen, which would be also indispensable to new growth, was not consumed at the rate of sugar, but was transferred to the growing stalks at a rate which left its proportion in the parent crown almost unchanged. Total ash was not reduced but largely increased as the organic matter was consumed. These points will be considered again in connection with the development of the tops of the plant.

ASPARAGUS STALKS.

The marketable portion of the asparagus plant consists of the young stalks cut from the crowns during the spring and early summer. Their constituents must be mainly derived from the reserve materials stored the previous summer in the roots, and the total quantity removed in a season represents the drain which the roots must be prepared to meet.

Our first samples of young stalks were obtained from the experiment field at Concord in 1910, but it was clearly evident that during the two or more days which elapsed between cutting in the field and delivery at the laboratory there were destructive changes taking place in the soluble carbohydrates or sugar of the cells. Consequently in the spring of 1911 a series of samples of young stalks was gathered from the experiment field at Amherst, which had been fertilized in a similar manner to the field at Concord.

Samples of stalks were cut from four different plots in the home field on four different dates, beginning May 17 and ending June 14. The stalks were cut as close to the crown as possible, and averaged about 10 inches (25 centimeters) in length. The common practice of asparagus growers in Massachusetts is to grow the crop so that most of the stalk is above ground, and when trimmed to the standard length of 8 inches (20 centimeters) it is nearly all green. The material used in our investigation represented the crop as cut from the crowns before it is bunched and trimmed. Each plot sample consisted of all the stalks which were tall enough to be marketable on the day of cutting.

Immediately after the samples were cut they were taken to the laboratory, where the stalks were wiped with a dry cloth to free them from adhering soil, after which the samples were weighed. The stalks were then broken into short pieces and spread on a tray which was placed in the steam-heated drying oven at a temperature of 55° to 60° C.

In preparing asparagus stalks for analysis it was found necessary to avoid a large amount of cut or broken surface, since the contents of the ruptured cells changed rapidly during the early drying stage by a process of fermentation with a loss of soluble sugar. Too high a temperature would soften the tender tips or buds of the stalks and cause them to stick to the tray. Pieces of stalks about 3 inches (7.5 centimeters) in length withered quickly in a temperature of 55° to 60° C., and at the end of twenty-four hours the largest butts were split in half, longitudinally, to promote further rapid drying. Samples dried in this manner were subsequently found to have retained their sugar unchanged, or at least under such conditions there was obtained the maximum proportion of sugar.

Composite samples from all plots represented each date of cutting, in order to determine the rate of change in their composition as the season advanced. The following table shows this composition: —

Composition of Asparagus Stalks in Spring.

[Parts in 100.]

	May 17.	June 1.	June 8.	June 14.
Water,	92.31	92.35	92.30	92.24
Dry matter,	7.69	7.65	7.70	7.76

Composition of Dry Matter.

	May 17.	June 1.	June 8.	June 14.
Ash,	8.77	9.07	8.47	8.47
Protein,	33.25	31.19	29.75	28.87
Fiber,	18.90	17.15	18.82	17.92
Fat,	2.84	3.03	3.20	3.22
Nitrogen-free extract,	36.24	39.56	39.76	41.52
Total sugars,	9.91	15.47	15.64	19.87
Reducing sugars,	7.75	11.66	12.04	13.22
Pentosans,	14.23	12.80	13.39	13.21
Lignin, etc.,	12.10	11.29	10.73	8.44
Total nitrogen,	5.32	4.99	4.76	4.62
Protein nitrogen,	3.07	3.06	2.99	3.15
Amino nitrogen,	2.25	1.93	1.77	1.47

Two notable sets of changes occurred in the composition of the series of samples.

Sugars increased remarkably in the successive periods, while protein and lignin decreased. Dry matter was practically constant. In 1914 two other lots of stalks were analyzed primarily for another purpose, but protein, sugar and dry matter behaved in a manner similar to that of the earlier samples.

	May 25.	June 2.
Dry matter,	7.64	7.68
Total sugar in dry matter,	20.55	27.39
Reducing sugar in dry matter,	14.25	20.29
Protein,	29.30	28.45

It seems probable that this change in amount of sugar is due to photosynthesis, since so much of the stalk is above ground and supplied with chlorophyl. Growth is somewhat slower as the season advances after the first rapid development in warm days of May, giving more time for the photosynthesis to go on. It does not seem reasonable that the drain on the roots should be inversely proportional to the reserves in them. The decrease in nitrogenous matter does follow the exhaustion of the roots. The change in protein is a steady decrease in the amino nitrogen, while the true protein remains practically constant. This points also to more self-support and slower growth.

Asparagus Tops.

The development of reserve food material by the asparagus plant has been studied by the analysis of samples of fully grown tops in midsummer and ripened tops in late fall. Two series of samples were collected from the fertilizer plots at Concord, — one in October, 1911, and the other in August, 1912. These were taken for the purpose of ascertaining whether the reserves were affected in any manner by the different fertilizers employed. Upon analyzing them it was noted that soluble carbohydrates were very low, and the possible destruction by respiration during the time required to transport the samples from Concord to Amherst led to taking parallel samples at Amherst for the study of their composition at the two stages of growth.

To avoid serious injury to the crowns, representative samples for each stage of growth were obtained by pulling only one stalk from a crown. Seven average plants yielded in this manner an abundance of material for a sample, and two parallel samples were thus selected on the different dates.

To ascertain how fast translocation of reserves was taking place the tops were divided into two portions. Each top was trimmed to a single stalk and thus was formed two samples, — stalks and branches.

The lot of tops was weighed as soon as removed from the field, then divided into stalks and branches, each portion being weighed. Each separate sample was now spread in the sun in the glass house for twenty-four hours, and then run through a fodder cutter. The samples were next dried in the large steam-heated oven until brittle enough to be ground, when they were cooled in the air, weighed and pulverized for subsequent analysis.

The summer stage of growth was after blossoming was about over, and the stalks chosen bore no berries. This stage was considered by analogy with other crops to be the stage of maximum growth of tops, and that the reserve material in the tissues would be at the maximum.

The ripened stage was when the stalks had turned yellow and the needles were falling from some of the stalks. The tops selected were those which shed but few when handled.

Composition of Asparagus Tops.

Seven stalks, Aug. 16, 1912, weighed, green, 1,791 grams. Branches were 60 per cent. and stems were 40 per cent. of total weight.

Seven stalks, Oct. 23, 1912, weighed, green, 1,859 grams. Branches were 64 per cent. and stems were 36 per cent. of total weight.

	SUMMER TOPS.		FALL TOPS.	
	Stems.	Branches.	Stems.	Branches.
Dry matter,	23.76	28.43	24.18	32.15
Ash in dry matter,	7.39	7.31	9.36	8.51
Protein,	7.94	17.31	4.47	11.00
Fiber,	44.83	29.76	45.11	32.02
Fat,	1.38	4.89	1.35	5.23
Nitrogen-free extract,	38.46	40.73	39.71	43.24
Total sugar,	14.28	8.68	9.34	7.09
Pentosans,	15.90	14.15	15.86	14.41
Lignin,	8.28	17.90	14.51	21.74
Reducing sugar,	12.50	2.99	8.76	3.99
Protein nitrogen,	1.03	2.42	.74	1.56
Amino nitrogen,	.24	.35	–	.20

Protein and sugar both disappear with ripening in about the same proportion, and appear to be the only groups of constituents subjected to translocation. The translocation of sugars as they are formed is indicated by the higher percentages in the stalks than in the branches, both in midsummer and in autumn.

In November (the 4th), 1914, six tops were gathered which were golden yellow in color but bare of needles. Dry matter, sugar and protein were determined with the following results: —

	Per Cent.
Dry matter,	49.45
Sugar,	4.08
Protein,	4.70

It is probable that neither sugar nor protein is completely transferred to the root, because until killed by frost the living cells must still contain active protoplasm and its supply of food.

The more extensive series of samples collected at Concord completely corroborate these changes in kind, but respiration undoubtedly affected the sugars. The average composition of the lots is given in the following table: —

Composition of Dry Matter.

	Summer Tops, 11 Samples.	Fall Tops, 7 Samples.
Ash,	9.34	8.65
Protein,	17.47	7.94
Fiber,	33.04	43.75
Fat,	2.71	3.49
Nitrogen-free extract,	37.44	36.17
Sugars,	5.29	–
Pentosans,	15.58	20.90
Lignin, etc.,	16.57	15.27
Total nitrogen,	2.79	1.27
Protein nitrogen,	1.63	1.27
Amino nitrogen,	1.16	–

Progressive Changes in Composition of the Asparagus Plant.

The following table has been arranged in order to compare the composition of the successive stages of growth which have been studied: —

	Autumn Roots, 1910.	Summer Roots, 1911.	Young Stalks.	Summer Tops.	Autumn Tops.
Water,	78.90	81.38	92.30	73.44	70.73
Dry matter,	21.10	18.62	7.70	26.56	29.27

Composition of Dry Matter.

Ash,	6.89	8.93	8.69	7.34	8.81
Protein,	12.44	12.75	30.77	13.56	8.65
Fiber,	19.77	23.66	18.20	35.79	36.73
Fat,	1.77	1.63	3.07	3.48	3.83
Total sugars,	31.52	23.20	15.22	10.92	7.90
Reducing sugars,	–	–	11.17	6.79	5.70
Pentosans,	10.96	11.66	13.41	14.85	14.92
Lignin by difference,	16.65	18.17	10.64	14.06	19.16
Total nitrogen,	1.99	2.04	4.92	2.17	1.38
Protein nitrogen,	1.05	1.30	3.07	1.86	1.26
Amino nitrogen,	.93	.74	1.85	.31	.12

The relation of water to intensity of growth is clearly shown by the changes in the proportion of water at the different stages of development. The summer roots procured in the midst of the growing season contained more water than the dormant roots obtained the fall before. The tops when just at their full height in midsummer were more watery than those that were ripening in the following October. But the most striking proportion of water was found in the tender, succulent stalks of spring and early summer at the period when growth is so rapid that it can be readily measured from hour to hour.

The active part performed by sugar is indicated by the difference in the percentages of this substance found in the various stages of the development of the plant. The large proportion of reducing sugar in the stalks and tops at the successive stages sampled, and its absence from the different series of roots, is in accord with distinction between active and reserve forms of sugars. The sugar in the roots at the seasons chosen for their study was wholly a reserve substance, and being readily soluble in water passed unchanged toward the actively growing stalks.

The insoluble non-nitrogenous substances which form the bulk of the plant at each stage of growth undergo the usual inverse changes in proportion which accompany the increase and decrease of more active constituents.

Amino compounds are an important part of the reserve nitrogenous material in the fall roots, as their nitrogen forms almost one-half of the total percentage of the element at that stage. This is a larger proportion than at any other stage, and points to its probable value for rapid transfer to the young stalks in the spring.

The Inorganic Constituents of the Asparagus Plant.

For comparing the progressive changes in the mineral constituents of the different stages of the asparagus plant we have used the averages of all results from the plots receiving complete fertilizers.

At first sight the average composition of the three series of roots appears to be practically alike, but a closer scanning reveals consistent variations in some of the constituents from year to year. Calcium, sulfur and sodium steadily increased in percentages from stage to stage in the roots, and also between the summer and fall stages of the tops. On the other hand, potassium, magnesium and phosphorus varied between narrow limits in the different stages of root development, and were noticeably diminished in the final ripening stage of the tops. These three elements are evidently translocated from the old tops to other parts of the plant, while the three first mentioned go in only one direction and accumulate as those parts of the plants grow older.

Sulfur is considerably in excess of phosphorus, which is unusual in our common garden crops. While no provision was made for this in planning the fertilizer, there was apparently enough of the element present in the stable manure or superphosphate used.

The translocation of potash, magnesia and phosphoric acid back to the roots is indicated but not proven, since there are the blossoms and berries to be considered as a possible destination in their transfer. These two sets of organs were not collected, however, as it was nearly impossible to get anything approaching accurate amounts of them from a series of stalks, because the red asparagus beetle destroys them in preference to other parts of the plant.

Inorganic Constituents of the Asparagus Plant at its Different Stages (Percentages in Dry Matter).

	Autumn Roots, 1908.	Autumn Roots, 1910.	Summer Roots, 1911.	Young Stalks.	Summer Tops.	Autumn Tops.
Calcium oxide, . . .	.316	.360	.436	.387	.994	1.635
Magnesium oxide, . .	.151	.192	.184	.346	.243	.190
Potassium oxide, . .	2.445	2.465	2.374	5.270	3.436	2.189
Sodium oxide, . . .	.245	.368	.366	.330	.203	.431
Phosphoric acid, . .	.507	.464	.442	.538	.472	.169
Sulfuric acid, . . .	.509	.627	.730	.833	.472	.532

EFFECT OF FERTILIZERS ON THE COMPOSITION OF THE ASPARAGUS PLANT.

The material for the study of the effects of fertilizers on the composition of the different parts of the asparagus plant was chiefly obtained from the experiment field [1] at Concord, but some was taken from the plots at the experiment station in Amherst.

The soil of the experiment field is typical of the soils chosen in Massachusetts for asparagus culture, *i.e.*, a coarse, sandy loam. Samples of the soil from four sections of the field were analyzed by the conventional method, and the results are given in the following table: —

Soil Analyses.

	Volatile Matter.	Insoluble Matter.	Calcium Oxide.	Magnesium Oxide.	Potasium Oxide.	Phosphoric Acid.	Sulfuric Acid.	Total Nitrogen.	Humus.
Surface.									
Southeast, . .	4.26	89.43	.20	.07	.09	.25	.04	0.13	1.97
Southwest, . .	4.55	89.86	.22	.02	.09	.21	.04	0.14	1.94
Northeast, . .	4.14	90.49	.23	.02	.10	.27	.04	0.13	1.85
Northwest, . .	4.25	90.27	.22	.01	.07	.20	.05	0.13	1.78
Subsoil.									
Southeast, . .	2.61	91.01	.08	.01	.09	.03	–	–	–
Southwest, . .	2.11	93.32	.13	.03	.09	.04	–	–	–
Northeast, . .	2.17	93.30	.06	.02	.10	.05	–	–	–
Northwest, . .	2.71	92.84	.04	.01	.08	.08	–	–	–
Second Foot.									
Southeast, . .	1.88	92.29	.07	.02	.10	.03	–	–	–
Southwest, . .	1.17	94.03	.09	.01	.12	.06	–	–	–
Northeast, . .	.79	95.62	.06	.04	.09	.05	–	–	–
Northwest, . .	.80	96.03	.06	.02	.09	.04	–	–	–

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[1] See annual reports for 1908 and following years for description of fertilizer experiments.

These analyses were made by Messrs. E. B. Holland and R. D. Maclaurin before the field was planted in 1907. It will be readily seen that the samples show a striking uniformity in composition.

The manner of fertilizing the experiment plots has been described in a previous paper,[1] but for the sake of clearness the scheme is here briefly outlined.

Plot.	Application.	Pounds per Acre, Nitrate of Soda.	Pounds per Acre, Acid Phosphate.	Pounds per Acre, Muriate of Potash.
1	No nitrates, ...	–	200.1	260.0
31	Low nitrate, in spring, ...	311.2	200.1	260.0
32	Low nitrate, in summer, ...	311.2	200.1	260.0
33	Low nitrate, half in spring, half in summer, . .	311.2	200.1	260.0
34	Medium nitrate, in spring, ...	466.6	200.1	260.0
35	Medium nitrate, in summer, ...	466.6	200.1	260.0
36	Medium nitrate, half in spring, half in summer, .	466.6	200.1	260.0
37	High nitrate, in spring, ...	622.4	200.1	260.0
38	High nitrate, in summer, ...	622.4	200.1	260.0
39	High nitrate, half in spring, half in summer, . .	622.4	200.1	260.0
40	No nitrate, ...	–	200.1	260.0
5	No phosphate, ...	466.6	–	260.0
6	Low phosphate, ...	466.6	133.4	260.0
7	Medium phosphate, ...	466.6	200.1	260.0
8	High phosphate, ...	466.6	266.8	260.0
9	No potash, ...	466.6	200.1	–
10	Low potash, ...	466.6	200.1	173.4
11	Medium potash, ...	466.6	200.1	260.0
12	High potash, ...	466.6	200.1	346.8

Effect of Fertilizers on Asparagus Roots.

The roots of 1908 represented only the plots that had received different applications of nitrate of soda; the samples of 1910 included these plots and the plots to which different quantities of acid phosphate and muriate of potash were applied. The weights of the roots are given by individuals and by plots in the following table: —

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[1] Ann. Rept., Mass. Agr. Expt. Sta. 25, p. 156.

Weights of Asparagus Roots when taken from the Field (Grams).

Series of 1908.

Plot.	Root I.	Root II.	Root III.	Root IV.	Plot Average.
1,	566	1,177	792	974	877
31,	1,268	883	1,177	770	1,024
32,	997	861	952	884	923
33,	1,020	635	1,020	907	895
34,	1,338	1,701	975	1,043	1,264
35,	1,360	1,134	680	1,927	1,275
36,	1,338	1,020	1,179	1,315	1,213
37,	1,542	1,224	1,179	1,406	1,338
38,	1,837	1,519	1,020	839	1,304
39,	544	1,020	476	884	731
40,	907	1,474	1,701	635	1,179

Series of 1910.

Plot.	Root A.	Root B.	Root C.	Root D.	Plot Average.
1,	2,262	2,070	1,816	1,951	2,025
5,	1,896	1,633	1,561	2,043	1,783
6,	2,960	3,012	2,573	2,868	2,853
7,	2,885	2,791	2,869	2,393	2,734
8,	2,182	2,265	1,833	2,703	2,246
9,	1,509	1,282	2,110	1,792	1,673
10,	2,827	3,015	1,993	1,745	2,395
11,	3,410	2,402	2,661	3,097	2,892
12,	1,986	2,967	2,691	3,194	2,709
31,	3,317	1,486	1,985	3,393	2,545
32,	1,918	2,570	1,526	2,000	2,003
33,	2,655	2,440	1,861	3,195	2,538
34,	3,540	2,119	2,677	2,595	2,733
35,	1,957	1,700	2,470	3,029	2,289
36,	2,043	4,432	2,282	3,598	3,089
37,	2,677	3,227	2,448	3,062	2,853
38,	2,807	2,313	2,446	1,676	2,310
39,	1,989	1,927	2,065	2,927	2,227
40,	3,042	1,717	2,197	1,967	2,231

There cannot be said to have been any specific effect of the nitrate of soda on the size of roots in 1908. The weights of the four roots from any given plot varied more widely among themselves than the plot averages differed from one another.

There were some consistent variations in the weights of the roots dug in 1910. The roots from plots 5 and 9, lacking phosphoric acid and potash, respectively, were consistently lower in weight than the roots from any other plot. The results of the absence of a nitrogen application to plots 1 and 40 were not positive because there were numerous roots from other plots receiving nitrogen that were no heavier individually, and the average weights for plots 32 and 39 were as small.

Comparing plot averages in the series 31 to 39, the average weights of roots from plots 32, 35 and 38 were consistently lower than those of the roots from plots 31, 34 and 37, which indicated the probable effect of a spring top-dressing to be an increase in the size of the roots. Nevertheless, the variations in weights of individual roots from any one of the plots is wide, and renders the conclusion from averages doubtful.

The effect of fertilizers on the inorganic constituents was thoroughly studied by the complete ash analysis of each root dug in 1908, and similar work on composite samples from the different plots in 1910. All the ash analyses were made in the fertilizer section by Messrs. H. D. Haskins and L. S. Walker, to whom the writer is indebted for the data which appear in the tables.

Inorganic Composition of Asparagus Roots (Percentages in Dry Matter).

Roots of 1908.

Plot.	Averages by Plots.						
	Total Ash.	Calcium Oxide.	Magnesium Oxide.	Potassium Oxide.	Sodium Oxide.	Phosphoric Acid.	Sulfuric Acid.
1,	5.53	.30	.14	2.12	.07	.44	.35
31,	5.96	.26	.14	2.03	.24	.48	.39
32,	6.63	.29	.13	2.62	.18	.56	.38
33,	6.61	.29	.15	2.33	.18	.52	.45
34,	7.12	.35	.16	2.62	.31	.55	.49
35,	6.46	.31	.16	2.51	.22	.48	.51
36,	6.49	.29	.14	2.23	.27	.49	.48
37,	6.41	.32	.14	2.15	.25	.52	.52
38,	7.01	.40	.16	2.44	.21	.56	.56
39,	6.41	.30	.14	2.47	.32	.47	.47
40,	5.89	.29	.12	2.45	.07	.50	.45

Inorganic Composition of Asparagus Roots — Concluded.

Roots of 1910.

PLOT.	AVERAGES BY PLOTS.						
	Total Ash.	Calcium Oxide.	Magnesium Oxide.	Potassium Oxide.	Sodium Oxide.	Phosphoric Acid.	Sulfuric Acid.
5,	6.81	.41	.18	2.36	.43	.47	.69
6,	7.09	.32	.16	2.66	.35	.46	.63
7,	7.54	.37	.21	2.73	.38	.46	.69
8,	7.34	.38	.19	2.55	.33	.49	.63
9,	5.94	.38	.19	1.44	.55	.44	.66
10,	6.17	.33	.18	2.10	.48	.42	.57
11,	6.18	.34	.19	2.21	.33	.46	.62
12,	7.10	.40	.20	2.53	.33	.48	.62

There was no specific effect of fertilizers observable in the ash constituents, except on plots 1 and 40 in the 1908 series, and plot 9 of the 1910 series. Soda was notably lower in the roots from the first-named plots, which had received no nitrate of soda, than in all other roots which had been dressed with that salt. The composite sample representing the last-named plot, which had received no potash salt, showed a much lower percentage of potassium oxide than any other sample of that year, and a small increase in sodium oxide.

The most notable fact observable in the ash constituents was the high percentage of sulfuric acid relatively to phosphoric acid. Withholding acid phosphate from plot 5 had no apparent effect in reducing either the phosphoric acid or the sulfuric acid in the sample from that area.

Total Nitrogen in the Dry Matter of Asparagus Roots.

Roots of 1908.

PLOT.	Root I.	Root II.	Root III.	Root IV.	Plot Average.
1,	1.21	1.29	1.36	1.30	1.29
31,	1.69	1.36	1.30	1.89	1.56
32,	1.96	1.93	1.65	1.54	1.77
33,	1.70	1.36	1.51	2.31	1.72
34,	2.43	2.01	2.18	2.12	2.18
35,	2.23	2.14	2.51	2.01	2.22
36,	1.56	1.92	2.05	2.16	1.92
37,	1.92	1.99	2.10	1.87	1.97
38,	2.20	2.51	2.51	2.19	2.35
39,	1.84	1.92	2.08	2.10	1.98
40,	1.50	1.22	1.21	1.20	1.28

Total Nitrogen in the Dry Matter of Asparagus Roots — Concluded.

Roots of 1910.

Plot.	Root A.	Root B.	Root C.	Root D.	Plot Average.
1,	1.67	1.77	2.05	1.69	1.79
5,	2.14	2.20	2.46	2.28	2.27
6,	2.12	2.25	1.93	1.97	2.07
7,	2.13	2.24	2.45	1.92	2.18
8,	1.94	2.08	1.99	2.15	2.04
9,	1.82	1.81	2.33	2.44	2.10
10,	2.40	1.98	1.61	2.18	2.04
11,	2.26	1.90	1.86	2.23	2.06
12,	1.91	2.27	2.25	1.87	2.07
31,	1.72	1.43	1.76	1.77	1.67
32,	1.81	1.96	2.02	2.23	2.00
33,	1.73	2.02	1.59	2.01	1.84
34,	2.02	2.02	1.89	1.99	1.98
35,	2.01	1.95	1.87	2.23	2.01
36,	2.07	1.79	1.91	2.00	1.94
37,	1.90	2.24	1.91	1.79	1.96
38,	2.32	2.07	2.60	1.89	2.22
39,	1.82	2.44	1.66	2.02	1.98
40,	1.59	1.30	1.06	1.22	1.29

Total nitrogen was determined in every root sample. The results individually and by plot averages are consistent. The absence of nitrogen in the top-dressing results in a low percentage of nitrogen in the roots from plots 1 and 40. The minimum and medium applications of nitrate show results on the percentages of nitrogen in the roots following the same order in relative quantities. The maximum application of nitrate of soda produced no result in excess of the medium application.

The application of the nitrate in midsummer was accompanied by a positively higher percentage of nitrogen in the roots from those plots, viz., plots 32, 35 and 38.

There was no apparent effect of fertilizers on the organic constituents of the roots, except that due to the influence on the nitrogenous group. High protein was accompanied by a lessened sugar percentage, but low sugar percentages also frequently occurred with low protein, in which condition there was a high fiber content. Consequently sugar and fiber fluctuated widely in samples from the same plot on account of some condition that was independent of fertilizers.

This wide fluctuation was most extreme in plot 9 of the 1910 series, and if the average for the plot were compared with those of the others in the series it would appear clearly to be an illustration of the effect of potassium on the formation of sugar; but there were two roots with normal percentages of sugar from the plot, while there were roots in plots 5, 7 and 8 which were abnormally low where muriate of potash was regularly applied in the normal quantity. It is the writer's opinion that these variations in sugars on this group of plots may have been due to an attack of rust in the summer of 1910, although special pains were taken to avoid plants which had thus suffered, when the sample roots were selected.

Furthermore, it is believed that there were two positively different types of plants in these series in mode of growth, viz., one type with numerous slender, long roots, and the other with fewer but thicker, fleshier roots. This fact was not noted soon enough to correlate the observations with the analytical data, but it is reasonable to assume that the slender roots would have more epidermis in proportion to volume than the fleshy roots, which renders it probable that the former would have more fiber and less sugar than the latter.

Organic Composition of Roots.

Roots of 1908.

Plot and Root.	Moisture.	Protein.	Fiber.	Sugars.	Pentosans.	Fat.
1 (I.),	2.09	7.37	14.91	47.12	–	–
1 (II.),	2.14	7.90	12.70	49.72	7.17	.80
1 (III.),	2.77	8.34	18.20	40.24	8.82	1.20
1 (IV.),	2.33	7.93	16.30	44.44	–	–
31 (I.),	2.00	10.36	15.07	42.28	–	–
31 (II.),	2.70	8.34	14.78	43.96	8.91	1.04
31 (III.),	2.16	7.93	14.92	44.36	9.00	.98
31 (IV.),	3.08	11.58	14.92	40.00	–	–
32 (I.),	2.37	12.07	15.10	–	–	–
32 (II.),	2.59	11.82	14.86	–	–	–
32 (III.),	2.18	10.10	13.98	42.00	8.25	1.05
32 (IV.),	2.59	9.45	18.22	38.04	9.18	1.05
34 (I.),	4.06	14.65	14.15	35.24	8.17	.56
34 (II.),	4.00	12.08	14.66	37.12	8.51	.68
34 (III.),	3.64	13.19	14.19	–	–	–
34 (IV.),	3.42	12.81	14.62	–	–	–
35 (I.),	2.06	13.69	17.23	36.00	8.46	1.09
35 (II.),	3.19	13.00	12.98	40.60	7.88	1.07
35 (III.),	4.31	15.12	15.22	–	–	–
35 (IV.),	3.34	12.13	15.26	–	–	–

Organic Composition of Roots — Continued.

Roots of 1908 — Concluded.

PLOT AND ROOT.	Moisture.	Protein.	Fiber.	Sugars.	Pentosans.	Fat.
37 (I.),	2.34	11.68	13.50	43.20	7.88	.81
37 (II.),	3.16	12.07	14.86	–	–	–
37 (III.),	3.01	12.69	13.52	–	–	–
37 (IV.),	2.91	11.32	18.31	33.16	9.65	1.20
38 (I.),	3.35	13.31	15.54	–	–	–
38 (II.),	3.02	15.27	17.40	24.28	10.24	1.13
38 (III.),	3.60	15.19	13.18	–	–	–
38 (IV.),	2.92	13.33	12.31	44.52	7.94	.84
40 (I.),	2.50	9.14	13.69	–	–	–
40 (II.),	2.71	7.31	13.91	–	–	–
40 (III.),	2.07	7.37	14.54	44.32	8.27	1.31
40 (IV.),	2.13	7.30	11.97	48.72	8.48	.87

Roots of 1910.

1 (A),	3.56	10.07	–	34.80	–	–
1 (B),	3.07	10.77	19.33	28.10	9.44	1.27
1 (C),	4.49	12.19	–	24.04	–	–
1 (D),	4.90	9.94	–	27.48	–	–
5 (A),	5.50	12.63	–	19.16	–	1.57
5 (B),	4.70	13.14	–	30.24	–	1.47
5 (C),	4.94	14.70	–	16.20	–	–
5 (D),	4.85	13.56	23.60	15.80	11.72	2.07
6 (A),	4.00	12.69	–	23.64	–	–
6 (B),	5.20	13.31	–	25.76	–	–
6 (C),	3.21	11.64	–	21.08	–	–
6 (D),	4.33	11.75	–	23.84	–	–
7 (A),	4.90	12.62	–	27.48	–	–
7 (B),	3.70	13.58	–	26.20	–	–
7 (C),	3.97	14.75	22.93	11.28	11.10	2.35
7 (D),	4.24	11.45	–	18.76	–	–
8 (A),	5.10	11.45	–	25.96	–	–
8 (B),	5.50	12.26	–	22.12	–	–
8 (C),	4.04	11.94	18.77	29.16	–	1.82
8 (D),	4.78	12.81	–	17.92	–	–
9 (A),	5.40	10.69	–	30.04	–	–

Organic Composition of Roots — Continued.

Roots of 1910 — Continued.

Plot and Root.	Moisture.	Protein.	Fiber.	Sugars.	Pentosans.	Fat.
9 (B),	6.20	10.58	–	24.08	–	–
9 (C),	4.21	14.01	25.10	11.04	11.79	1.87
9 (D),	4.65	14.63	21.76	9.56	11.63	2.42
10 (A),	5.40	14.26	–	28.32	–	–
10 (B),	5.40	11.69	–	33.28	–	1.47
10 (C),	3.61	9.63	–	23.64	–	–
10 (D),	4.56	13.06	–	29.40	–	–
11 (A),	4.20	13.62	–	30.68	–	–
11 (B),	5.40	11.20	–	30.44	–	–
11 (C),	4.03	11.05	16.35	32.84	–	1.77
11 (D),	4.27	13.39	–	30.88	–	–
12 (A),	5.20	11.23	–	32.64	–	–
12 (B),	5.30	13.50	17.36	33.28	–	1.22
12 (C),	3.62	13.62	–	27.48	–	–
12 (D),	3.59	11.26	–	28.12	–	–
31 (A),	4.95	10.13	–	39.48	–	–
31 (B),	4.48	8.41	–	32.40	–	–
31 (C),	3.42	10.51	–	–	–	–
31 (D),	3.28	10.56	–	30.88	–	–
32 (A),	3.47	10.80	–	31.12	–	–
32 (B),	3.54	11.75	–	32.84	–	–
32 (C),	4.70	12.00	–	27.04	–	–
32 (D),	4.93	13.25	–	23.20	–	–
33 (A),	3.63	10.33	–	34.60	–	–
33 (B),	3.60	12.08	–	29.25	–	–
33 (C),	4.55	9.37	–	33.08	–	–
33 (D),	4.42	11.94	–	25.32	–	–
34 (A),	3.58	12.91	16.83	30.68	10.71	1.30
34 (B),	3.49	12.92	15.83	41.36	9.87	1.37
34 (C),	4.67	11.25	–	30.88	–	–
34 (D),	4.90	11.82	–	29.60	–	–
35 (A),	3.69	12.08	–	33.70	–	–
35 (B),	3.42	11.69	–	38.92	–	–
35 (C),	4.88	11.04	–	35.88	–	–
35 (D),	4.00	13.38	–	39.60	–	–
36 (A),	2.58	12.63	17.24	34.30	–	1.72

Organic Composition of Roots — Concluded.

Roots of 1910 — Concluded.

Plot and Root.	Moisture.	Protein.	Fiber.	Sugars.	Pentosans.	Fat.
36 (B),	5.53	10.51	17.83	28.32	–	1.40
36 (C),	4.19	11.40	–	29.80	–	–
36 (D),	4.27	11.94	–	25.76	–	–
37 (A),	4.49	11.31	–	35.24	–	–
37 (B),	4.74	13.44	–	32.00	–	–
37 (C),	3.40	11.50	–	33.28	–	–
37 (D),	4.18	10.69	–	35.44	–	–
38 (A),	3.95	13.94	–	39.80	–	–
38 (B),	4.32	12.37	–	36.96	–	–
38 (C),	3.96	15.70	–	25.32	–	–
38 (D),	4.41	11.20	–	36.12	–	–
39 (A),	4.28	10.87	–	37.30	–	–
39 (B),	4.64	14.63	–	35.04	–	–
39 (C),	3.69	9.94	–	33.28	–	–
39 (D),	3.54	12.19	–	26.60	–	–
40 (A),	3.42	9.56	–	38.08	–	–
40 (B),	3.51	7.81	17.13	38.20	9.04	1.22
40 (C),	3.25	6.32	–	33.08	–	–
40 (D),	3.70	7.32	–	35.04	–	–

EFFECTS OF FERTILIZERS ON ASPARAGUS STALKS.

An attempt was made to determine the effect of fertilizers on the composition of the young stalks, and on that of the tops in midsummer and late fall.

On May 13, 1910, the day's crop from each of four plots in the Concord field was shipped by Mr. Prescott to the laboratory at Amherst. The four samples represented three plots dressed with the maximum amount of nitrogen and one plot which received no nitrogen. The analyses were limited to determinations of dry matter, ash and total nitrogen, and the results were as follows: —

	With Nitrogen.			No Nitrogen, Plot 40.
	Plot 37.	Plot 38.	Plot 39.	
Dry matter,	7.00	6.50	6.80	6.10
Ash in dry matter,	10.14	10.57	9.81	10.76
Nitrogen in dry matter,	4.72	4.55	4.57	4.49

There was a small variation in favor of the plots dressed with nitrogen in both nitrogen and dry matter.

On May 17, 1911, a series of samples was collected in a similar manner from the home field in Amherst, where the material could be prepared for drying as soon as cut. These samples represented one plot without nitrogen, one without phosphoric acid, one without potash and one with a complete fertilizer. Nitrogen and dry matter were determined, and the figures are arranged below.

	No Nitrogen.	No Phosphoric Acid.	No Potash.	Complete Fertilizer.
Dry matter,	8.04	7.50	7.61	7.57
Nitrogen in dry matter,	5.33	5.31	5.17	5.47

In this series there was again a slight gain in nitrogen in the sample from the plot receiving a complete fertilizer, but there was no effect on the dry matter.

On June 1, June 8 and June 14 the entire day's crop from each of four plots was saved and analyzed. These plots represented variations in quantities of nitrogen, phosphoric acid and potash applied as a dressing. The results are shown below for dry matter and nitrogen.

PLOT.	DRY MATTER.			NITROGEN IN DRY MATTER.		
	June 1.	June 8.	June 14.	June 1.	June 8.	June 14.
N+P+K,	7.61	7.65	7.72	5.00	4.72	4.61
2N+P+K,	7.49	7.70	7.73	4.89	4.77	4.37
N+2P+K,	7.62	7.63	7.51	5.12	4.87	4.68
N+P+2K,	7.91	7.84	7.90	4.98	4.67	4.84

There was little effect on the composition of the young stalks to be perceived by comparing the results of the first plot with those of each of the other plots. The dry matter varied within narrow limits, while the nitrogen showed a progressive decrease as the season advanced, which was independent of the fertilizers. There was a slight but consistent advantage shown by the double quantity of potash on dry matter results from the last plot.

EFFECTS OF FERTILIZERS ON ASPARAGUS TOPS.

The period immediately following blooming was chosen as one of the stages of growth at which to study the effect of fertilizers on the development of reserve material in the tops for translocation to the roots. Up to this period the asparagus plant increases steadily in size, and presumably draws continuously through its roots on the soil for its required mineral matter while building up its organic matter in its green branches. There has been probably but little transfer of sugars and proteins to the roots during this growing time, and it seemed as if any effect of the fertilizers on the formation of those constituents should be perceptible at this season.

The material for this study was gathered from the experiment field at Concord by the selection of samples of tops from eight of the fertilizer plots, which represented wide variations in the method of fertilization. In order to disturb the subsequent growth of these plots as little as possible, not more than one stalk was removed from any plant. Each sample consisted of six stalks selected from as many typical plants on a plot. The samples were weighed immediately after being gathered, and were then packed in burlap sacks for shipment to the laboratory at Amherst. The samples were gathered on Aug. 13, 1912, and were delivered at the laboratory forty-eight hours later.

On the arrival of the samples at the laboratory they were again weighed and were found to have lost 13 per cent. of their field weight, of which loss a large part must have been due to respiration and the consequent destruction of sugars. The branches were cut from the main stalks, and the latter broken in short pieces to facilitate drying, which was carried out by spreading the samples on benches in the greenhouse. It was not possible to dry all the samples simultaneously in the oven, so the greenhouse was selected as providing uniform conditions for them. At the end of five days each sample was cut into short lengths by a fodder cutter, after which a small subsample was separated by quartering.

The small samples were next dried in the oven until they were in a condition to be easily ground, when they were pulverized and passed through a millimeter sieve.

Weights of Samples of Green Tops (Pounds).

Plot 1,	5.25
Plot 5,	6.60
Plot 9,	5.25
Plot 11,	6.75
Plot 31,	6.25
Plot 32,	6.25
Plot 34,	6.15
Plot 35,	5.65

The absence of nitrogen on plot 1 and of potash on plot 9 was accompanied by the lightest weights of samples. Plots 11 and 34 received equal amounts of the complete fertilizer in the spring, and their samples exceeded in weight those of 1 and 9. The absence of phosphoric acid from plot 5 did not affect the weight.

Just before the needles had dropped in the fall was selected as another stage at which to study the effect of the fertilizers on the composition of the tops and on the development of reserve material. For this purpose Mr. Prescott was asked to procure some samples from the Concord field.

In accordance with our instructions Mr. Prescott selected four average plants on each of the plots from which a sample was desired, and removed the entire tops from the crowns. Each plot sample was wrapped in paper and then put in a jute sack for shipment to the laboratory.

The samples arrived at the laboratory on October 23 with the outer sacks somewhat wet as though rained upon, which was not unlikely since the period was especially rainy. On opening the sacks the tops were found to be damp, and a slight mold was observed on some of the twigs. The material was cut into short lengths with a fodder cutter and spread above the steam coils in the greenhouse.

A few days later the samples were quartered and the subsamples were dried in the steam-heated oven until they could be readily ground and sifted.

Partial Composition of Asparagus Tops.

Midsummer Tops.

	Plot 1.	Plot 5.	Plot 9.	Plot 11.	Plot 34.
Ash in dry matter,	10.61	9.00	8.55	9.21	9.69
Protein,	17.87	17.00	17.44	17.56	18.50
Fiber,	32.62	33.62	31.58	34.34	–
Ether extract,	2.46	2.70	3.04	2.66	–
Sugars,	5.11	5.32	6.33	4.41	4.96

Late Fall Tops.

	Plot 1.	Plot 5.	Plot 9.	Plot 11.	Plot 34.
Ash in dry matter,	12.12	7.84	6.68	–	8.97
Protein,	8.44	8.31	7.50	–	8.62
Fiber,	41.89	44.93	46.30	–	41.23
Ether extract,	3.68	3.28	3.56	–	3.40
Pentosans,	20.71	21.44	21.60	–	20.14

Partial Composition of Asparagus Tops.

Midsummer Tops.

	Plot 31.	Plot 32.	Plot 34.	Plot 35.
Ash in dry matter,	9.58	10.33	9.69	8.70
Protein,	17.44	17.12	18.50	17.94
Sugars,	5.66	5.00	4.96	3.75

Late Fall Tops.

	Plot 31.	Plot 32.	Plot 34.	Plot 35.
Ash in dry matter,	8.90	7.95	8.97	8.06
Protein,	8.12	7.50	8.62	7.06
Pentosans,	20.46	21.15	20.14	20.83

Plot 1 lacked nitrogen, plot 5 lacked phosphoric acid and plot 9 lacked potash. Plots 11 and 34 received the complete fertilizer in medium amount. Plots 34 and 35 received one and one-half times the amount of nitrogen that was applied to 31 and 32. Plots 31 and 34 received their nitrogen in the early spring, while 32 and 35 had their portions applied in late June.

The high ash occurring in both seasons in the tops from plot 1 was apparently due to fine earth which adhered to them, as there was much insoluble residue after testing the ash with strong acid. On the other hand, the samples from plot 9 showed a low ash, which was without doubt due to the lack of potash.

The development of protein and sugar was not perceptibly affected by the lack of fertilizers, since there is no consistent relation between the percentages and the amounts.

A comparison of the two pairs of plots which received nitrogen at different seasons shows that the tops from the plots dressed with nitrates in summer contained slightly less protein than those from the plots dressed in the spring. This was also the result on the single pair of plots (37 and 38) from which the young stalks were sampled in 1910. With the two pairs of plots under comparison there was a slight advantage in the amounts of protein found in the tops from the larger quantities of nitrogen.

The effect of fertilizers on the proportions of inorganic constituents in the different stages of tops was not studied because the slight effects produced on the roots did not warrant such a laborious comparison.

Effect of Fertilizers on Asparagus Roots at the End of the Cutting Season.

The summer samples of roots were dug from plots receiving two different quantities of nitrogen at two different seasons for the purpose of measuring whether the exhaustion of the roots during the growth of the crop was influenced by amount or season of application of nitrate of soda. Plots 34 and 35 received one and one-half times as much nitrogen as 31 and 32, while 31 and 34 received it in the spring and 32 and 35 in the summer.

Total nitrogen and sugar showed consistent variations relative to the different treatments, but none of the other constituents could be correlated and are not tabulated.

The roots dressed with the larger amount of nitrogen contained higher percentages of nitrogen and sugar than those which received the smaller amount. Roots receiving their nitrogen in summer after the cropping season still contained a little more nitrogen than the others. Sugar, however, was more exhausted than in the roots which had received their nitrogen in spring.

Comparative Effects of Spring and Summer Top-dressing on Asparagus Roots at End of Cutting Season.

Plot and Root.	Fresh Weight (Grams).	Per Cent.		
		Dry Matter.	Total Nitrogen.	Total Sugar.
31 (I.),	600	17.15	1.37	22.40
31 (II.),	2,744	21.37	1.78	34.54
31 (III.),	1,995	18.52	2.24	19.92
31 (IV.),	1,970	19.77	1.86	26.17
Average,	1,825	19.20	1.81	25.76
32 (I.),	1,400	16.04	1.94	19.60
32 (II.),	2,060	15.87	2.06	7.68
32 (III.),	3,830	14.43	2.47	7.40
32 (IV.),	3,375	19.97	1.79	18.53
Average,	2,666	16.58	2.06	13.30
34 (I.),	2,750	17.88	1.84	26.43
34 (II.),	3,150	19.81	1.80	32.67
34 (III.),	3,400	20.58	2.22	36.14
34 (IV.),	1,805	15.59	2.33	16.13
Average,	2,776	18.46	2.06	27.84
35 (I.),	2,945	18.88	2.12	29.87
35 (II.),	860	23.14	2.22	31.17
35 (III.),	3,180	21.25	2.18	26.70
35 (IV.),	2,355	17.67	2.10	15.27
Average,	2,335	20.24	2.15	25.90

Sugar fluctuated widely in individual roots, and the value of the averages is somewhat doubtful.

The weights of roots from the same plot vary as widely as the weights from different plots, so that no conclusions can be drawn from the size of roots.

The general effect of varying the season of top-dressing with nitrate of soda was very small and inconclusive.

RESERVE MATERIAL REQUIRED TO PRODUCE A CROP OF YOUNG STALKS.

An attempt is here made to determine the amount of reserve material drawn from the roots during the spring cutting season. For this purpose use is made of the average composition of fall roots, spring stalks and summer roots, and the average weights obtained from the four plots numbered, respectively, 31, 32, 34 and 35 of fall roots, summer roots and the spring crop of stalks.

The calculated results are necessarily approximate because identical roots cannot be analyzed at two successive stages of growth, but the comparison suggests possibilities if not absolute conditions.

The average weights of roots were obtained from the samples collected in 1910 and 1911. The average weight of the crop of stalks is calculated from the total weights cut on the four plots in 1911. The number of plants per plot was originally 250, but four roots were removed in 1908 and four more in 1910.

Grams of Constituents in Roots and Crop of an Average Plant.

	Autumn Roots, **1910.**	Summer Roots, **1911.**	Spring Crop, **1911.**
Green weight,	2,393.00	2,401.00	447.00
Dry matter,	504.90	447.00	34.40
Total sugar,	159.24	103.70	5.23
Fiber, pentosans and lignin,	239.22	239.10	22.25
Fat,	8.93	7.28	1.05
Protein,	62.81	56.99	10.52
Ash,	34.78	39.91	2.97
Total nitrogen,	10.05	9.12	1.68
Protein nitrogen,	5.35	5.81	1.05
Amino nitrogen,	4.70	3.31	.63
Potassium oxide,	12.44	10.61	1.80
Sodium oxide,	1.85	1.63	.11
Calcium oxide,	1.81	1.95	.13
Magnesium oxide,	.97	.82	.12
Phosphoric acid,	2.34	1.97	.18
Sulfuric acid,	3.12	3.26	.28

The average weight of crop per plot was 238.6 pounds (108.3 kilos) which, divided between 242 plants, gave a little less than a pound, or 447 grams, per plant.

When the combined weights of the different constituents of summer roots and spring crop were balanced against the weights of the same constituents in the autumn roots there was noted a marked loss in organic matter and a pronounced gain in inorganic matter.

The loss of organic matter was confined almost wholly to the sugar, as there was but a small deficit in the quantity of fat. The total carbohydrate matter in the spring crop amounted to 27.48 grams, while the difference between the quantities of sugar in the autumn and summer roots was 57.54 grams. There was an increase in protein of 4.7 grams over the amount present in the autumn roots, which might require a little of the sugar in its synthesis; but, on the other hand, the study of the progressive changes in composition of young stalks indicated that they synthesized a part of their sugar before they were of marketable size. Therefore the comparison in this case showed that for every gram of carbohydrate developed in the young stalk at least two grams disappeared from the parent root, one of which must have been used in maintaining the energy of the growing plant, just as the young animal uses a large part of its food in maintaining its body energy.

The gain in protein during the growth of the crop is of interest in connection with the problem of nitrogen fertilization. The transfer of nitrogen from the autumn root to the growing stalk was apparently accomplished by using only the amino nitrogen of the reserve in the parent crown, and drawing on the soil nitrogen. The increase in nitrogen of summer roots and crop over the amount in the autumn roots is .75 gram, or 7.5 per cent., and is not of sufficient amount to show the necessity of a spring application of nitrogen.

The gain in ash was confined to calcium oxide and sulfuric acid of the determined constituents, while a part of the variation was undoubtedly due to the very fine sand of the soil which had escaped the cleaning process to which roots and stalks were subjected.

Calcium oxide and sulfuric acid gained, respectively, .27 gram and .42 gram, or 14 per cent. and 13 per cent. Potassium oxide and magnesium oxide were almost exactly balanced on the two sides, while sodium oxide and phosphoric acid had slight amounts unaccounted for, which may have been due to the difficulties in exact determinations of these constituents in organic substances.

These comparisons show but little, if any, immediate effect on the spring crop of a spring application of fertilizers. There was a slight apparent absorption of nitrogen, a more marked intake of lime and sulfuric acid, perhaps in combination, and no apparent use at this period of potash and phosphoric acid. But as already remarked, these comparisons can be regarded as merely suggestive.

Amount of Vegetable Matter contained in Ripened Asparagus Tops.

The method of asparagus culture now followed by many growers in Massachusetts leaves the tops to die down in the autumn and in the spring works them into the soil by means of a disc harrow. On the experiment field a number of the plots have received no annual dressing of manure, and the humus in the soil has been replenished only by the annual growth of tops.

In the autumn of 1912 Mr. Prescott was requested to determine the weights of the ripened tops on several plots that had received only chemical fertilizers. Mr. Prescott selected one rod of row on each plot, where there were seven consecutive plants to the rod. The stalks were cut level with the ground and weighed.

This work was done in the last week in October when the sap had mostly left the stalks.

The weights per plot were as follows: —

Weights of Tops per Rod of Row, Autumn of 1912 (Pounds).

Plot 1, without nitrate of soda,	3.5
Plot 3, complete fertilizer,	5.5
Plot 5, without acid phosphate,	4.0
Plot 7, complete fertilizer,	4.0
Plot 9, without muriate of potash,	4.0
Plot 11, complete fertilizer,	6.5
Plot 34, complete fertilizer,	4.0
Plot 40, without nitrogen,	3.0
Average,	4.3

At the rate of 250 plants per plot, or 5,000 plants per acre, these results from 7 plants would give 3,071 pounds of dying tops per acre. Samples of stalks gathered early in November at Amherst contained 49 per cent. of dry matter, by which it is estimated that there were about 1,500 pounds per acre of dry vegetable matter added to the soil of the asparagus field per year.

Rousseaux and Brioux[1] report, as the result of five different fields in France, a range of from 891 to 2,128 kilos per hectare for the dry matter in the crops of the tops removed in late autumn from the fields, in accordance with French practice. Their average dry matter per hectare was 1,579 kilos, or about 1,400 pounds, per acre.

In percentage of soil per acre this amount of tops is really small. On such sandy soil as the Concord field the tops would be worked into the surface 4 inches, or mixed with approximately 1,000,000 pounds of soil, which would enrich the soil with not more than .15 per cent. of organic matter. Nevertheless, several of the best plots in the experiment field have received no more organic matter than is contained in the tops, which is a good illustration of the effectiveness of small annual additions of organic matter to our soils.

RELATION OF ASPARAGUS ROOTS TO WEIGHTS OF STALKS.

It was expected that there would be a close relationship found between the size of roots from a plot and the total weight of stalks cut from it, and an attempt was made to correlate the weights of sample roots in 1910 with the weights of crops over a period of five years.

In the phosphate group of plots, 5, 6, 7 and 8, the smallest roots were obtained from the plot that received no phosphate in the top-dressing; but the crop yields were not invariably the lowest in the series. Plot 8, which received the maximum dressing of acid phosphate, yielded much smaller roots than plots 6 and 7, but its crop yield was the maximum in every year but the fifth, when its yield was exceeded by plot 7 with a fraction of a pound.

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[1] Annal. d. Sci. Agron., 1906, pp. 188-326.

The weight of roots in the potash group of plots numbered 9, 10, 11 and 12 increased from 9 without potash to 11 with a medium application. The yield of stalks followed the same order each year.

The nitrate of soda group included ten plots numbered 31 to 40, inclusive. The weights of individual roots from any one plot varied considerably from the average for that plot, but the plot averages showed fairly consistent changes in size of roots with amount of nitrogen applied in the top-dressing. The weights of roots from plots 31, 32 and 33 were, respectively, smaller plot by plot than the weights of roots from plots 34, 35 and 36. The weights of crops did not follow the same order, but were in several instances reversed.

The application of nitrate of soda in the spring on plots 31, 34 and 37 resulted in much larger roots than the summer dressing apparently produced on 32, 35 and 38. On the other hand, the weights of crops from the summer-dressed plots were in nearly all cases the larger. Plot 40 without nitrate yielded roots no lighter in weight than plot 39, which received a maximum dressing of nitrate of soda, divided between spring and summer. The yield of stalks was, however, much smaller on plot 40 than on 39. The small roots with large yields contained higher percentages of nitrogen than the roots bearing smaller crops, so there was difficulty in correlating roots with crops of stalks, since the variations in proportions of root constituents were possible factors in influencing growth of stalks.

Weight of Asparagus Stalks cut in the Spring (Pounds).[1]

Plot.	APPLICATION.	1910.	1911.	1912.	1913.	1914.
5	No phosphate,	232.3	221.1	270.9	388.0	404.2
6	Minimum phosphate,	241.4	221.1	273.4	385.8	420.4
7	Medium phosphate,	241.6	240.4	281.1	387.7	436.9
8	Maximum phosphate,	252.8	251.6	298.4	403.3	436.4
9	No potash,	208.6	210.6	258.6	324.0	366.7
10	Minimum potash,	237.2	237.3	284.7	373.6	408.4
11	Medium potash,	276.5	289.9	342.0	446.8	478.9
12	Maximum potash,	262.7	269.6	302.8	409.8	458.5
31	Minimum nitrate, spring,	220.9	223.7	272.4	375.1	395.7
32	Minimum nitrate, summer,	221.3	242.2	284.4	401.6	406.3
33	Minimum nitrate, half in spring, half in summer,	222.6	239.7	291.2	378.4	389.8
34	Medium nitrate, spring,	214.2	240.6	288.0	381.9	378.6
35	Medium nitrate, summer,	216.0	247.8	288.9	368.3	368.5
36	Medium nitrate, half in spring, half in summer,	210.2	224.2	268.5	357.4	362.2
37	Maximum nitrate, spring,	193.9	223.2	283.8	345.2	340.9
38	Maximum nitrate, summer,	196.2	234.9	303.0	367.1	347.5
39	Maximum nitrate, half in spring, half in summer,	214.2	230.7	288.4	358.6	351.6
40	No nitrate,	181.2	202.2	263.4	307.5	314.3

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[1] For Table of Weights of Roots see p. 278, series of 1910.

SUMMARY.

During the earlier years of the asparagus field the crowns and roots steadily increased in size, doubling in weight between the second and fourth years after setting. The proportion of protein remained nearly constant in the dry matter of the roots during the period observed, while the sugar decreased and the cellulose and allied compounds increased.

The composition of the young stalks cut in the spring changed as the cutting season advanced. Dry matter was practically constant, but sugar increased in proportion while protein decreased somewhat.

The development of the asparagus tops to maturity was accompanied by a continuous increase in the cellulose and its related groups, — pentosans and lignin. Protein and sugar decreased in their proportions, but were not wholly translocated to the roots from the ripened tops.

Water was the dominant constituent of the asparagus plant in all the stages studied. It was highest in the young stalks. The summer or growing roots were a little more watery than the late fall or storage roots.

Calcium oxide and sulfuric acid steadily accumulated in the asparagus tops as they grew old, but potash and phosphoric acid were transferred either to the fruit or back to the roots.

Withholding one of the constituents of a complete fertilizer from the annual top-dressing was accompanied by a smaller average weight of roots in the samples taken from the plot thus treated. Withholding nitrate of soda lessened the percentage of nitrogen and of soda in the roots; withholding muriate of potash lessened the proportion of potash in the roots; withholding acid phosphate produced no apparent change in the constituents of the roots.

An increase of nitrate of soda from the minimum to the medium amount in the top-dressing caused an increase in the percentage of nitrogen in the dry matter of the roots.

An increase in the amount of muriate of potash produced some increase in the percentage of potash in the roots.

Asparagus roots taken from plots receiving the nitrate of soda in the spring were noticeably heavier in weight and a little poorer in nitrogen than roots from plots that were top-dressed with nitrate in the summer.

During the cutting season the production of young stalks drew most heavily on the sugar contained in the roots, but there was no approach to exhaustion of that constituent. Fully twice as much sugar was consumed as would have been required to produce the carbonaceous matter in the young stalks.

The roots apparently absorbed nitrogen, lime and sulfuric acid during the cutting season. Potash and phosphoric acid were apparently supplied to the young stalks wholly from the reserves in the roots.

PRACTICAL CONCLUSIONS FROM THE CHEMICAL STUDY OF THE ASPARAGUS PLANT.

Asparagus roots that had been set in the spring of 1907 were found to have doubled in size and weight between November, 1908, and November, 1910. During this period of rapid growth the percentages of the different fertilizing constituents in the dry matter remained constant or else increased slightly.

Absence of nitrogen, phosphoric acid or potash from the annual top-dressing was found to limit the growth of the roots.

Withholding nitrate of soda from the top-dressing, or applying it in relatively small amounts, resulted in lessening the percentages of nitrogen in all parts of the plant.

A complete fertilizer rich in nitrogen is clearly shown to be required in generous amounts in order to produce a continuous strong development of the asparagus plant.

Water is of prime importance in all parts of the asparagus plant at all stages of growth. It is especially important in the spring months during the cutting season, since the young stalks contain about 92 per cent. of water, while the roots at this period are more watery than in the fall. The physiological need of water, together with the sandy quality of most asparagus soils, indicates that irrigation would be advantageous if not necessary in the production of maximum crops.

The reserve material stored in autumn in the roots was found to be principally sugars. Sugars were also prominent in the spring stalks and both summer and fall tops. The synthesis of sugar in the tops and its translocation to the roots appeared to continue until the tops were killed by frost.

Destruction of the tops by rust, or their premature removal to be rid of the berries, must lessen the amount of sugar which can be stored in the roots.

The fertilizing constituents which were stored in the roots over winter appeared to be nearly, if not quite, sufficient for the full development of the succeeding spring crop. There was evidence of a small intake of nitrogen during the cropping season, and a pronounced absorption of lime and sulfuric acid.

Sulfuric acid was found to be equally, if not more, important than phosphoric acid among the constituents of the asparagus plant. Nevertheless, the sulfate of lime in the acid phosphate appeared to suffice fully for the needs of the crop.

BULLETIN No. 172 MARCH, 1917

MASSACHUSETTS
AGRICULTURAL EXPERIMENT STATION

EXPERIMENTS IN KEEPING ASPARAGUS AFTER CUTTING

By F. W. MORSE

The object of this experiment was to determine some of the changes which take place in asparagus from the time when it is cut in the field until it is ready to be cooked. It is not usually desirable to hold asparagus more than a few days to prevent market gluts. The usual methods of keeping asparagus at summer temperatures cause rapid deterioration in quality, and should be remedied if a discriminating patronage is desired.

Requests for bulletins should be addressed to the
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Amherst, Mass.

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Publication of this Document
approved by
The Supervisor of Administration.

BULLETIN No. 172.

DEPARTMENT OF CHEMISTRY.

EXPERIMENTS IN KEEPING ASPARAGUS AFTER CUTTING.

BY F. W. MORSE.

The object of this experiment was to determine some of the changes which take place in asparagus from the time when it is cut in the field until it is ready to be cooked. This period varies from a few hours to several days, and during it there is seldom any care taken to preserve the asparagus stalks in a fresh, crisp condition. Sometimes the stalks are kept with their butts in water; but this is not a general practice among the dealers in this vegetable.

Fruits and vegetables are living things and life is maintained by respiration, which requires a supply of food just as with animals. When animals fast they lose weight because their body material is used in respiration. When vegetables and fruits are removed from the plants on which they grew they steadily lose in weight because of respiration, and their chemical composition continually changes.

Experiments with apples [1] have clearly shown that after the fruit is picked from the tree respiration is maintained by which carbon dioxide and water are continually exhaled, while analysis has proved that sugar steadily diminishes and the fruit loses in weight. It was found, too, that low temperatures slowed down the respiration while high ones speeded it up, and that retarding respiration was an important factor in the preservation of fresh fruits.

Besides investigating the nature of the change in asparagus after it has been cut from the plant, the effects of high and low temperatures on the rate of change have been studied as an important part of the experiment.

The following table [2] gives the average composition of asparagus stalks when prepared for analysis as soon as practicable after they were cut from the plants: —

TABLE I.

Composition of Asparagus Stalks when Fresh (Per Cent.).

Water,	92.30
Dry matter,	7.70

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[1] F. W. Morse: The Respiration of Apples and its Relation to their Keeping. Bul. 135, N. H. Agr. Expt. Sta., 1908, 8 pp.

Bul. 171, Mass. Agr. Expt. Sta., p. 274.

Per Cent. in Dry Matter.

Ash,	8.69
Protein,	30.77
Fiber,	18.20
Fat,	3.07
Total sugars,	15.22
Reducing sugars,	11.17
Pentosans,	13.41
Lignin, etc.,	10.64

It will be noted that the succulent stalks contained over 92 per cent. of water, and that protein, fiber and sugar were the most abundant constitutents of the dry matter. Fiber forms the framework of the stalks, while the protein and sugar are the substances utilized most freely by the cells for food and growth. The two latter substances were studied as the means of determining the kind and rate of change occurring in the asparagus after cutting.

Several experiments were conducted, each one varying a little in detail from its predecessor; therefore each experiment will be separately described.

Two were conducted in 1914 and the remainder in 1916.

Experiment 1. — This experiment was begun May 25, 1914. A quantity of stalks was brought to the laboratory immediately after they were cut in the field. Each stalk was rinsed clean from adhering soil and wiped dry with a towel. The lot was then divided into three bunches of uniform size and appearance, and each bunch was weighed and placed under its assigned conditions.

One bunch, A, was prepared at once for quick drying. The stalks were broken into pieces 2 to 3 inches long, which were spread in a single layer on a tray and placed in a large drying oven. The oven was heated by a steam coil which maintained a temperature between 50° and 60° C. This heat was sufficient to expel the water from the succulent stalks without softening them, as in cooking.

The second bunch, B, was set in a jar with the butts in shallow water and left in the laboratory where the temperature would remain at summer heat, or from 70° to 80° F. day and night.

The third bunch, C, was loosely wrapped in paper and laid on the shelf in a refrigerator of the usual family size, kept well supplied with ice, which held the temperature between 45° and 50° F.

At the end of three days (seventy-two hours), bunches B and C were again wiped dry with towels and weighed, after which they were prepared for the drying oven in the same manner as A.

B was firm and brittle and had increased in weight over 15 per cent. by imbibing water. C was somewhat limp but not withered, and had lost a little over 3 per cent. of its original weight.

When dried to a condition which permitted the asparagus to be easily ground to a powder, the samples were removed from the large oven, weighed and pulverized. The samples were then analyzed for absolute dry matter, total sugar, reducing sugar, protein, protein nitrogen and amino nitrogen, and the results are arranged in Table II.

TABLE II.

	A.	B.	C.
Weight fresh (grams),	823	804	803
Weight after keeping (grams),	–	927	776
Per Cent. calculated on Fresh Weight.			
Water,	92.36	93.20	92.75
Dry matter,	7.64	6.80	7.25
Per Cent. in Dry Matter.			
Total sugars,	20.55	10.41	14.11
Reducing sugars,	14.25	9.94	10.10
Total protein,	29.33	34.33	30.75
Protein nitrogen,	3.72	3.28	4.01
Amino nitrogen,	.97	2.21	.91

Experiment 2. — This experiment was begun June 2, 1914, and was carried out as nearly as possible in the same manner as Experiment 1, and the data are given in Table III.

TABLE III.

	A.	B.	C.
Weight fresh (grams),	715.5	719.5	719.0
Weight after keeping (grams),	–	836.0	698.5
Per Cent. calculated on Fresh Weight.			
Water,	92.32	93.19	92.72
Dry matter,	7.68	6.81	7.28
Per Cent. in Dry Matter.			
Total sugars,	27.39	12.41	18.91
Reducing sugars,	20.29	7.46	12.68
Total protein,	28.46	32.90	31.39
Protein nitrogen,	3.49	3.57	3.92
Amino nitrogen,	1.06	1.69	1.10

Although B imbibed water and increased in weight, there was really greater destruction of dry matter than in the bunch C, which was kept in the refrigerator. The actual amount of change under each condition is shown on the basis of 100 parts of fresh asparagus in Tables IV. and V.

TABLE IV. — *Experiment 1.*

	A.	B.	C.
Dry matter (per cent.),	7.64	6.80	7.25
Sugar (per cent.),	1.57	.71	1.02
Protein (per cent.),	2.24	2.34	2.23

Protein was little changed, but sugar was partly destroyed. The loss of sugar was a little in excess of the loss of dry matter.

TABLE V. — *Experiment 2.*

	A.	B.	C.
Dry matter (per cent.),	7.68	6.81	7.28
Sugar (per cent.),	2.10	.84	1.37
Protein (per cent.),	2.19	2.24	2.28

There was a marked change in the relative proportions of protein nitrogen and amino nitrogen in B in both experiments, as shown in Tables II. and III. The chemical activity changed the form of nitrogen compounds but not their total amount, as shown in Tables IV. and V.

The work was not continued in 1915 on account of other investigations that seemed more important. In the spring of 1916 the investigation was resumed and several different experiments were conducted.

Experiment 3. — This experiment was begun May 29, 1916. This lot of stalks was brought to the laboratory from the plots as soon as cut. The plots had not been cut over for two days and the stalks were too tall and the heads had begun to open too much for good marketable asparagus. The stalks were washed and scrubbed with a brush to remove all adhering soil, and wiped dry with towels. The lot was then separated into five bunches as uniform as possible in appearance, after which each bunch was weighed and placed under its assigned conditions.

A was broken in short pieces, spread on a tray and placed in the oven at a temperature between 50° and 60° C. B was set upright in a jar with the butts in water and left in the laboratory at the room temperature. C was wrapped loosely in paper and laid on the shelf beside B. D was laid directly upon the cake of ice in the refrigerator. E was stood upright in a jar with its butts in water and set in the food compartment of the refrigerator.

At the end of forty-eight hours bunches B, D and E were unbound and the stalks were wiped with towels. C, having been kept dry, needed no such drying. Each bunch was then weighed, after which it was prepared and put in the oven as A had been.

The stalks in B were firm and crisp, but the heads were much opened. The stalks in C were limp and slightly withered, and a few would not break, but were cut into the proper lengths for drying. Those in D, lying directly on the ice, were somewhat limp but unwithered, while those in E, standing in the water, were plump and firm, and the heads were unchanged in appearance. Both B and E had imbibed water, but B had gained almost 15 per cent. in weight, while E had gained only 10 per cent. C and D both lost weight; the former shrunk 21.7 per cent., while the latter lost only 3.7 per cent.

Dry matter and total sugar were the only determinations made after the dried stalks were pulverized for analysis.

TABLE VI.

	Weight Fresh (Grams).	Weight after Keeping (Grams).	Dry Matter from Fresh Weight (Per Cent.).	Total Sugars from Dry Matter (Per Cent.).
A, ...	677	–	6.72	15.96
B, ...	654	751	6.47	12.14
C, ...	590	512	6.30	12.35
D, ...	714	688	6.65	14.63
E, ...	633	697	6.49	11.23

Experiment 4. — This experiment was begun June 5, 1916. The material was much like that of the previous experiment, — a little too much developed for the best marketable condition. The stalks were washed and dried and arranged in five bunches which were subjected to conditions like those of Experiment 3. B and C were held but twenty-four hours, while D and E were continued throughout four days (ninety-six hours). B, in twenty-four hours, imbibed water and increased in weight 16.8 per cent. E, in four days, increased 13.7 per cent. Of the bunches kept dry, C, in the warm room, lost 8.2 per cent. in twenty-four hours, and D, on the ice, lost 5.4 per cent. in four days.

The determinations in the dried material were confined to dry matter and sugar.

TABLE VII.

	Weight Fresh (Grams).	Weight after Keeping (Grams).	Dry Matter from Fresh Weight (Per Cent.).	Total Sugars from Dry Matter (Per Cent.).
A,	528	–	7.50	20.60
B,	534	624	7.18	16.31
C,	549	504	7.31	17.34
D,	589	557	7.34	17.91
E,	544	619	7.20	17.99

Experiment 5. — The stalks were brought to the laboratory on the morning of June 15, 1916. The weather for two days had been cooler than usual, so that the asparagus had grown less rapidly than at the time of the two previous trials. The stalks were about 10 inches long, with close heads. The lot was divided into six bunches, A, B, C, D, E and F.

As usual, A was prepared for the drying oven at once. The other five bunches were stood upright in a tin box with a tight cover and with no water in it. The box with its contents was placed in the refrigerator.

The two previous experiments had shown that the asparagus stalks would become limp even when on the ice, unless their butts were in water. The tight box was chosen in order to reduce the evaporation to the lowest point by keeping the stalks in a close atmosphere. This atmosphere was soon saturated with moisture by the exhalations from the stalks, but there was no water for imbibition. The imbibed water promotes chemical activity, and the stalks with butts in water, while remaining firm and crisp, actually lose dry matter more rapidly than those held out of water, which become limp, as shown by B and E when compared with C and D in Tables VI. and VII.

One bunch at a time was removed from the box, at intervals of two to four days.

June 19, four days after cutting, B was taken out. Stalks were firm and crisp, apparently as fresh as when placed in the box. Drops of moisture appeared on the walls of the box and on the stalks. The stalks were wiped dry with a towel and then weighed. After being weighed the stalks were broken and spread on a tray and dried in the oven as usual.

June 21, six days after cutting, C was removed. Stalks were apparently as sound and fresh as B. Subsequent treatment was as usual.

June 23, eight days after cutting, D was removed. The stalks in this bunch were slightly limp, but not as limp as bunches kept on ice for a day or two in the circulating atmosphere of the refrigerator. The bunch was treated as usual.

June 26, eleven days after cutting, E was removed. The stalks were firm and plump, but this may have been due to imbibition of water through the butts, as there was now a positive accumulation of exhaled moisture on the bottom of the box. The refrigerator temperature held at 45° to 50° F.

June 29, fourteen days after cutting, F was taken out. The stalks were firm and crisp. The butts looked dry and old on their surfaces; but if freshly trimmed by cutting off one-fourth of an inch of their length, the bunch would have passed for freshly cut asparagus. Much moisture had accumulated on the bottom of the box. The stalks were prepared for drying in the usual manner.

The usual determinations of dry matter and total sugar were made in the dried material.

TABLE VIII.

	Weight Fresh (Grams).	Weight after Keeping (Grams).	Dry Matter from Fresh Weight (Per Cent.).	Total Sugars from Dry Matter (Per Cent.).
A,	528	–	6.76	17.76
B,	535	531	6.73	20.20
C,	474	470	6.79	19.39
D,	512	504	6.64	20.65
E,	453	444	6.25	13.79
F,	578	570	6.00	9.87

There was one unaccountable discrepancy in this series, — A had a lower sugar content then B, C or D. There may have been some condition during the first hours of drying this sample which favored the transformation of sugar into some of the lignified matter, but that is mere conjecture. Ordinarily, a lowering in sugar has been accompanied by a pronounced lessening of dry matter, which did not appear in this instance.

Experiment 6. — This experiment was begun June 19, 1916. The stalks were a poor average lot, some having grown too tall and having heads much opened, but a portion of the stalks were in excellent form for market. The lot was divided into four bunches of as uniform quality and size as could be estimated.

Bunch A was immediately prepared for drying in the accustomed manner. The other three bunches were set upright in the tin box with those of Experiment 5, and none of them was removed until July 5, sixteen days after cutting. As a whole, these three bunches were in poor condition when taken out. Some of the tips were attacked by a white mold and some of the butts were soft with decay. Some stalks were shriveled throughout their length. The stalks were wiped dry with towels and weighed. Then all stalks showing signs of decay or mold were rejected from further study, and the remainder was sorted into firm and shrunken lots. Of the original lot of stalks, 34 per cent. was rejected, 35 per cent.

was firm and crisp in appearance, and the remaining 31 per cent. was more or less shrunken or withered.

These latter two lots of stalks were prepared for analysis in the customary manner, and dry matter and total sugar were determined.

TABLE IX.

	Weight Fresh (Grams).	Weight after Keeping (Grams).	Dry Matter from Fresh Weight (Per Cent.).	Total Sugars from Dry Matter (Per Cent.).
A,	519	–	6.24	20.54
B, C, D,	1,769	1,714	–	–
Firm,	–	–	5.32	2.53
Shrunk,	–	–	5.38	3.83

This lot of stalks proved quite inferior in dry matter to any of the other lots; but in total sugar, A was equal to any of the others of this season.

To determine whether the loss of sugars was the only destructive change in the dry matter, the losses of both sugars and dry matter were compared, as shown in Table X. It was noted that in all but two instances, namely, Experiment 3, C, and Experiment 4, E, the loss of sugar slightly exceeded the shrinkage in dry matter. This excess though small was persistent.

TABLE X.

Comparative Losses of Dry Matter and Sugars (Per Cent.).

	DRY MATTER.			TOTAL SUGARS.		
	Originally.	After Keeping.	Loss.	Originally.	After Keeping.	Loss.
Experiment 1, **A**,	7.64	–	–	1.57	–	–
B,	–	6.80	.84	–	.71	.86
C,	–	7.25	.39	–	1.02	.55
Experiment 2, **A**,	7.68	–	–	2.10	–	–
B,	–	6.81	.87	–	.84	1.26
C,	–	7.28	.40	–	1.37	.73
Experiment 3, **A**,	6.72	–	–	1.07	–	–
B,	–	6.47	.25	–	.78	.29
C,	–	6.30	.42	–	.78	.29
D,	–	6.65	.07	–	.97	.10
E,	–	6.49	.23	–	.73	.24
Experiment 4, **A**,	7.50	–	–	1.54	–	–
B,	–	7.18	.32	–	1.17	.37
C,	–	7.31	.19	–	1.27	.27
D,	–	7.34	.16	–	1.31	.23
E,	–	7.20	.30	–	1.29	.25
Experiment 5, **B, C, D**,	6.72	–	–	1.35	–	–
E,	–	6.25	.47	–	.86	.49
F,	–	6.00	.72	–	.59	.76
Experiment 6, **A**,	6.24	–	–	1.28	–	–
Firm,	–	5.32	.92	–	.13	1.15
Shrunk,	–	5.38	.86	–	.20	1.08

The disappearance of the sugar is probably, in part, a transformation into the cellulose group of carbohydrates. This view was suggested by the work of Mrs. K. G. Bitting, who kindly allowed me to read the proof sheets of her bulletin on "Deterioration in Asparagus,"[1] in which she has shown that asparagus tissues develop increasing areas of lignin when the stalks are kept for twenty-four hours or more after being cut from the crown.

In order to elucidate further the character of the changes in the groups of constitutents in the asparagus, Mr. C. L. Beals determined the crude fiber and fat in the dry matter of the six samples described in experiments 1 and 2. The results are given in per cent. of dry matter and absolute weights calculated in the fresh stalks

TABLE XI.

Per Cent. in Dry Matter.

	A Fresh.	B Kept Warm.	C Kept Cool.
Experiment 1: —			
Fiber,	10.54	15.51	12.71
Fat,	2.74	2.04	2.75
Experiment 2: —			
Fiber,	10.99	17.59	13.01
Fat,	2.85	2.29	2.94

Grams in Fresh Material.

	A	B	C
Experiment 1: —			
Dry matter,	7.64	6.80	7.25
Fiber,	.80	1.05	.92
Gain,	–	.25	.12
Fat,	.21	.14	.20
Loss,	–	.07	.01
Experiment 2: —			
Dry matter,	7.68	6.81	7.28
Fiber,	.84	1.19	.95
Gain,	–	.35	.11
Fat,	.22	.15	.21
Loss,	–	.07	.01

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[1] K. G. Bitting: Bulletin 11, National Canners' Association, Washington, D. C., 1917, 18 pp. 9 plates.

This series of determinations fully corroborated the increase of lignified tissue, as there was a positive gain in the absolute amounts of crude fiber or cellulose in the samples held for three days, which gain was more than twice as great in the warm room. At the same time there was a positive loss of the fatty extract in the warm room, but an almost negligible shrinkage in the refrigerator.

The pronounced destruction of sugar by respiration and the increase of lignified tissue must affect the flavor and tender crispness of the young stalks, and these changes were much lessened by the lower temperatures.

The development of fiber or cellulose at the expense of sugars and fatty matter is a logical consequence of the continued growth of asparagus stalks after they have been cut from the crown. The comparative amounts of this growth at summer temperatures and the cooler ones of the refrigerator have been studied with interesting results.

Freshly cut stalks of asparagus were divided into two lots, one of which was left in a warm room over night, or about ten hours, while the other was placed in the refrigerator for the same period. Both lots of stalks stood with butts in shallow water.

The temperatures of room and refrigerator were noted at the beginning and end of the period, and as neither was opened during the time, it was assumed that the temperatures had remained within the limits noted. The increase in length of each stalk was carefully measured. The total number of stalks used in the different trials was 25. The average results for each trial are tabulated in Table XII.

TABLE XII.

	Temperature (Degrees F.).	Growth (Millimeters).	Temperature (Degrees F.).	Growth (Millimeters).
June 2,	75–76	12.3	52–56	4.3
June 4,	70–71	14.3	49–54	2.5
June 7,	68–71	11.7	49–54	4.0
June 20,	80	18.6	45	2.6

The average rate of growth in the warm room was more than four times as fast as that in the refrigerator. At no time was the refrigerator cold enough to stop entirely the elongation of the tips, but at 45° F. it was nearly negligible.

Summarizing the results of these varied experiments, it is clear that in Experiments 1 and 2, the changes in the warm room were fully double those in the refrigerator. In Experiment 3, the bunches in the warm room changed three times as fast as the bunch on ice. In Experiment 4, the bunches in the warm room changed more in one day than those in the refrigerator changed in four days. In Experiment 5, the asparagus changed very little in a week, when kept in a close atmosphere in the refrigerator. Experiment 6 showed that two weeks was too long a period to hold asparagus under the conditions.

In conclusion, the experiments clearly show the possibility of holding asparagus for a week with very little deterioration in quality, by keeping the stalks at a low temperature and in a close atmosphere with little air circulation. The temperature should be as low as 45° F. if possible, as this point is about the lowest limit for plant growth to take place, although respiration, or the destruction of sugar, will still persist.

Experiments on a commercial scale have not been tried, but the feasible plan appears to be as follows: cool the asparagus as soon as possible after cutting. Lay the stalks loosely in boxes, place on ice in the icehouse and cover with canvas to maintain a low temperature and reduce the circulation of air. The common market boxes would probably allow any moisture exhaled and later condensed to drain off and not accumulate in the bottom of the box. Under this treatment the asparagus should not deteriorate appreciably in three or four days, when it may be bunched and trimmed to the proper length. By this treatment the market gluts occurring on account of Sundays and holidays, or hot waves, can be tided over with better prices and less waste.

Any prolonged holding of asparagus in cold storage is a problem not yet studied. It presents a different set of conditions from those of most other vegetables or fruits.

Fruits and most vegetables are matured storage organs of plants, and their structure and composition are adapted to preservation for a longer or shorter time. Asparagus, on the contrary, consists of the youngest stage of the plant at the period of most active growth. Its external and internal structures are adapted to rapid change in composition and development. The cell protoplasm persists in its activity at a reduced rate, while the delicate cuticle favors evaporation of the cell moisture and the attack of external molds. Hence, it is a difficult matter to arrest the changes and permanently hold the stalks in their pristine tenderness and flavor.

It is not usually desirable to hold asparagus more than a few days to prevent market gluts. The usual methods of keeping asparagus at summer temperatures cause rapid deterioration in quality, and should be remedied if a discriminating patronage is desired.

BULLETIN No. 173 MAY, 1917

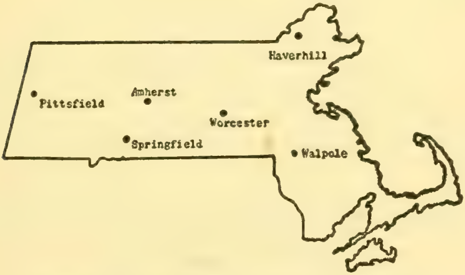
MASSACHUSETTS

AGRICULTURAL EXPERIMENT STATION

THE COST OF DISTRIBUTING MILK IN SIX CITIES AND TOWNS IN MASSACHUSETTS

By ALEXANDER E. CANCE and RICHARD HAY FERGUSON

Department of Agricultural Economics Co-operating with
the Office of Markets, United States Department of Agriculture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Location of Cities and Towns Covered in this Investigation.

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[1] On leave.

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PUBLICATION OF THIS DOCUMENT
APPROVED BY THE
SUPERVISOR OF ADMINISTRATION.

BULLETIN No. 173.

DEPARTMENT OF AGRICULTURAL ECONOMICS.

THE COST OF DISTRIBUTING MILK IN SIX CITIES AND TOWNS OF MASSACHUSETTS.[1]

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FOREWORD.

The facts presented in this bulletin show that the cost of distributing retail milk by more than 80 distributors, some of them producers, some of them dealers, was 2.64 cents a quart in 1914 and 1915. It cost 42 distributors in Worcester and Springfield 2.79 cents a quart on the average.

These costs included (1) all labor costs — labor hired, labor of the members of the family, labor of the operator and proprietor in preparing the milk for delivery, and delivering it (labor made up more than half of the total cost); (2) all depreciation or replacement costs on all buildings, equipment and horses used in preparation or delivery; (3) all maintenance charges, or cost of upkeep of plant and equipment — repairs, oil, bottles, etc.; (4) all overhead or fixed charges and all supplies used but once — rent, interest, taxes, insurance, license, soap, caps, light, fuel, stationery, bad debts, spoilage, etc. The charges made were adequate and the figures obtained mean that, according to the accounts and statements of 85 distributors, the average milkman in 1914 and 1915 was able to pay himself wages and interest and account for all expenses and losses when he received from his retail customers 2.64 cents more than he paid for a quart of milk delivered at his plant; or 2.79 cents if he lived in Springfield or Worcester.

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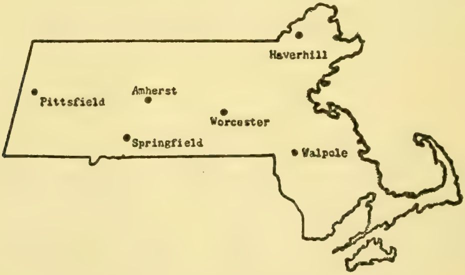
[1] Practically all of the data for this bulletin were personally collected by the late Professor Richard Hay Ferguson, who was responsible also for most of the tabulations and for much of the bulletin in its present form. Mr. Ferguson died Dec. 1, 1915. This bulletin was his last work.

Prices have risen since 1915. Labor and supplies of all kinds are higher. Just how much the increase has been cannot be stated with accuracy. Retail food prices have advanced nearly 30 per cent. Perhaps 25 per cent. will fully cover the advance in milk-distributing costs.

Assuming the increase to be 25 per cent. the cost of retailing milk in the fall of 1916 would probably average 3.30 cents per quart for all distributors here cited and 3.49 cents per quart for the milkmen investigated in Springfield and Worcester. The authors will not, however, vouch for these figures. Actual present costs may be higher or lower than 3.30 cents or 3.49 cents.

Introduction.

It is well known that for a number of years the price of milk to the consumer has been increasing. Not long ago milk was retailed at 6 cents a quart, whereas to-day the price is 9, 10 and, in many instances, 11 cents. Producers complain that notwithstanding the increased price paid by consumers they are, at the prices paid to them, producing milk at a loss and unless some change is made whereby they can get a fair return for their product, the whole dairy industry in Massachusetts is doomed. On the other hand the consumers view with alarm the increase in price and cannot understand why they must pay 10 cents a quart for milk when the producer is receiving but 4½ to 5½ cents net.



Location of Cities and Towns Covered in this Investigation.

The Problem.

The milk question has many phases and many relations. Some of these have been indicated in the very enlightening bulletin on the milk situation in New England, issued in June, 1915, by the Boston Chamber of Commerce.

The Massachusetts Agricultural College, in its outline of the problem, has recognized three important lines of study and investigation:

1. The cost and methods of production.
2. Collection and primary transportation of milk and cream.
3. Methods and costs of distributing; *i.e.*, preparing for delivery and delivering milk and cream.

Closely related with all three is the problem of milk inspection.

Problems 1 and 2 are quite as important as No. 3, the cost of distribution, but this preliminary study deals mainly with distribution and incidentally with transportation. Several studies have been made of the cost of producing milk in the North Atlantic States but, in the authors' opinion, none of these deal with the problem of milk production on the typical dairy farms of New England in a detailed and thoroughgoing way over a sufficiently long period.[1] Comparatively little serious work has been done on the methods and cost of transporting milk.

Co-operative Investigation.

The Department of Agricultural Economics of the Massachusetts Agricultural College and the Office of Markets of the United States Department of Agriculture formulated a plan for making an accurate, first-hand study of milk distribution in a number of Massachusetts cities and towns, perhaps the first study of its kind ever organized.

The data used in this study were collected by agents of the Department of Agricultural Economics and the Office of Markets during the fall of 1914 and the winter of 1915. Altogether, rather accurate data were obtained from 85 distributors of milk, each of whom was visited from one to several times in order to obtain as reliable figures as possible. Several of the tabulations were made by the Federal Office of Markets, where all the figures were checked.

Scope of the Investigation.

Recognizing the fact that the cost of distribution may vary according to the size and location of a town or city, as well as with the size and method of doing business, it was decided to investigate three groups of towns.

Amherst and Walpole, each having a population approximating 5,000, — the former a college town in the Connecticut valley and the latter an industrial center in the southeastern part of the State, — were chosen as typifying small town conditions in different parts of Massachusetts. Both Amherst and Walpole draw their supply of milk from the immediate neighborhood. The greater portion of Amherst's milk is distributed by dealers, while that of Walpole is marketed by the producers themselves.

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[1] Harwood, P. M.: What it costs to produce Milk in New England. Mass. State Bd. of Agr. Cir. No. 9. Boston, Mass., 1914. Hopper, H. A., and Robertson, F. E.: The Cost of Milk Production. Cornell University in co-operation with Jefferson County Farm Bureau, Bul. No. 357. Ithaca, N. Y., 1915. Lindsey, J. B.: Record of the Station Dairy Herd and the Cost of Milk Production. Mass. Agr. Exp. Sta. Bul. No. 145. Amherst, Mass., 1913. Rasmussen, Fred: Cost of Milk Production. New Hampshire Coll. and Exp. Sta. Exp. Bul. No. 2. Durham, N. H., 1913. Thompson, A. L.: Cost of producing Milk on 174 Farms in Delaware County, N. Y. Cornell Univ. Bul. No. 364. Ithaca, N. Y., 1915. Trueman, J. M.: Records of a Dairy Herd for Five Years. Storrs Agr. Exp. Sta. Bul. No. 73. Storrs, Conn., 1912.

Haverhill and Pittsfield, industrial centers of approximately 30,000 population each — the former in the northeastern part of the State, in the midst of good dairy farms which supply the requirements of the city, and the latter in the heart of the Berkshires in western Massachusetts surrounded mainly by the homes of summer residents and drawing its milk supply from a greater distance — form the second group.

Springfield and Worcester, commercial and manufacturing cities of over 100,000 population, constitute the third group, the one located in the Connecticut valley, where the land is given over chiefly to the raising of tobacco, onions and other intensive crops, while the other is situated in the center of Massachusetts' best dairying county. Naturally, in Worcester and Haverhill a rather large portion of the milk is distributed by the producers themselves. In some cases the producers distribute not only the product of their own dairies but also that of neighboring farmers, thus in a measure becoming middlemen.

TABLE I. — *Firms interviewed, classified by Location and Quantity of Retail and Wholesale Milk, Cream and Skim Milk handled daily.*

PLACE.	Total Dealers.	300 Quarts and under.	301–500 Quarts.	501–1,000 Quarts.	1,001–2,000 Quarts.	Over 2,000 Quarts.	All Wholesale.	Handling only Cream and Skim Milk.
Amherst,	5	3	2	–	–	–	–	–
Walpole,	5	3	2	–	–	–	–	–
Haverhill,	22	4	8	7	1	–	–	2
Pittsfield,	12	3	3	2	3	–	1	–
Worcester,	31	4	10	10	3	2	1	1
Springfield,	11	3	2	2	3	1	–	–
Totals,	86	20	27	21	10	3	2	3
Per cent. of number,	100	23	31	24	12	3.5	3	3.5
Routes,	170	22	38	42	38	25	2	3

In each locality sufficient typical distributors were interviewed to insure the reliability of the figures and the representative nature of the facts. The distributors interviewed and the volume of business represented were as follows: —

PLACE.	Distributors interviewed.	Quarts of Milk and Cream distributed daily.	Total Number of Distributors in Locality.	Total Quarts daily Distribution Estimates.
Amherst,	5	1,320	5	-
Walpole,	5	1,409	5	-
Pittsfield,	12	7,690	46	-
Haverhill,	22	10,828	40	20,000
Worcester,	31	22,809	167	75,000
Springfield,	11	10,149	110	65,000

In Amherst, Walpole, Haverhill and Pittsfield about 60 per cent. of the total milk distributed is represented. In Springfield there are approximately 65,000 quarts distributed daily, and in Worcester 75,000. The figures presented include approximately 16 per cent. of the Springfield distribution and 30 per cent. of that in Worcester.

Some idea of the size of the milk business in Worcester and Springfield and the number and character of distributors may be gained from Tables II. and III. These figures were obtained in April and September, 1916. It is interesting that Springfield is supplied from 694 sources, the milk passing through the hands of 608 distributors handling a daily average of 27 gallons each. The average milkman in Springfield sells 118 gallons of milk and cream daily; in Worcester, 107 gallons.

TABLE II. — *Springfield, Sources, Quantities and Methods of securing City Milk and Cream Supply.*

SOURCES OF SUPPLY.	Number.	APPROXIMATE DAILY QUANTITIES.		Number of City Dealers supplied directly.
		Milk (Gallons).	Cream (Gallons).	
Producers hauling to city,	15	1,025	25	-
Individual producers shipping to city,	650	14,480	-	-
Country creameries and milk stations,	24	-	500	-
Farmers' stations,	5	-	-	-
Totals,	694	15,505	525	560

TABLE II. — *Springfield, Number of Milk Distributors and Approximate Quantities handled* — Con.

CLASSES OF MILK DISTRIBUTORS.	Number of Distributors.	Number of Routes.	APPROXIMATE NUMBER OF GALLONS SOLD DAILY.						
			Raw Milk.	Pasteurized Milk.	Special Milk.	Fermented Milk.	Certified Milk.	Cream.	Total Gallons.
Producers: —									
Retail,	15	15	750	-	150	-	-	25	925
Wholesale,	2	2	285	-	50	-	75	-	410
City distributors: —									
Retail,	75	127	6,250	2,500	-	-	-	50	8,800
Wholesale,	18	-	1,250	1,000	-	300	-	325	2,875
Licensed retail stores,	400	-	950	750	-	-	-	60	1,760
Hotels, saloons and restaurants,	98	-	750	750	-	-	-	65	1,565
Totals,	608	144	10,235	5,000	200	300	75	525	16,335

TABLE III. — *Worcester, Number of Milk Distributors and Approximate Quantities distributed.*

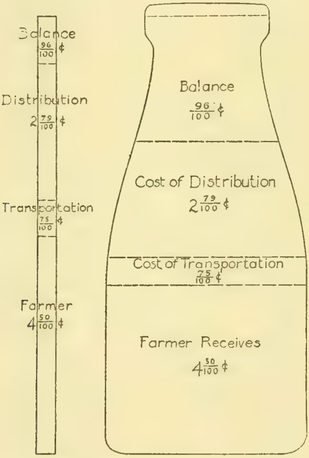
KIND OF DISTRIBUTORS.	Number of Dealers.	Number of Routes.	AVERAGE NUMBER OF GALLONS SOLD DAILY.						PER CENT. OF TOTAL GALLONS SOLD.	
			WHOLE MILK.		SKIM MILK.		CREAM.			
			Wholesale.	Retail.	Wholesale.	Retail.	Wholesale.	Retail.	Wholesale.	Retail.
Producers,	80	89	875	2,260	6	6	9	9	28.2	71.8
City dealers,[1]	87	180	4,672	8,693	1,068	134	935	134	42.6	57.4
Totals,	167	269	5,547	10,953	1,074	140	944	143	41.6	58.4

[1] Practically all the milk and cream sold by city dealers is shipped to the city by rail.

PROCESSING COSTS AND DELIVERY COSTS.

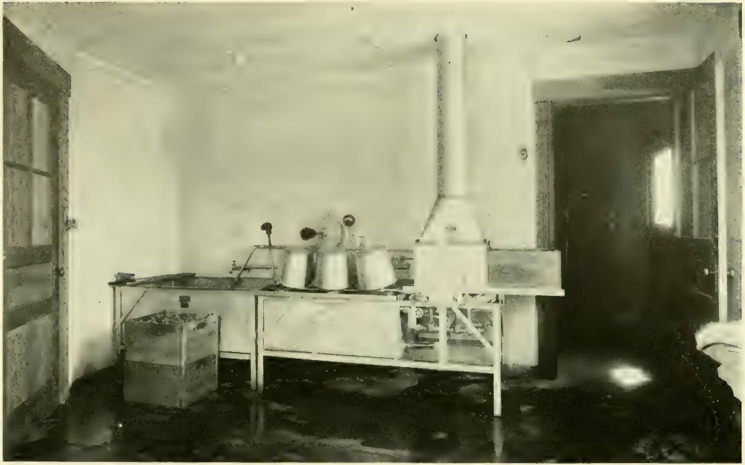
The costs of distributing milk fall naturally into two classes — preparation for delivery or processing, and delivery to customers. The transportation of milk from the producer to the dealer is an additional item of expense, but usually the producer delivers his milk to the dealer. In this study the transportation cost has not been considered. The analysis of costs begins with the preparation of the milk for delivery and ends with the collection of money from customers.

Simple as this analysis appears, a number of items cannot well be charged exclusively either to preparation or to delivery — administration and clerical expenses, light, telephone, etc.; insurance and taxes, perhaps; shrinkage, spoilage and bad debts. In the summary of costs these have been called "overhead" expenses; usually they might well be distributed between processing and delivery.



When the consumer pays 9 cents.

From the standpoint of health, pure, clean milk is as necessary as a good water supply. Milk just drawn from a healthy cow under sanitary conditions is at its best, and could it reach the consumer in this condition it would be ideal. To preserve it and to overcome the bad effects of unhealthy stock, unsanitary methods and conditions in the barn and reduce to a minimum the unavoidable deterioration in handling, transit and storage, milk has to be "prepared" for the customer. This preparation may be called "processing," and, so far as the distributors interviewed



Equipment every distributor should have.

were concerned, consists chiefly in cooling the milk and bottling, *i.e.*, washing, filling and capping the bottles. Milk is almost universally delivered to the consumer in bottles; in fact, only one instance of dipped milk was discovered; this was in Worcester.

In addition to this, however, some of the larger dealers clarify their milk by running it through a machine which removes the visible dirt, or pasteurize it to retard bacterial development. This materially adds to the cost of processing. Tables II and III show that only a minor percentage of the milk distributed in Springfield is pasteurized.

In Haverhill, of 20 distributors visited, but 2 had pasteurizers. In Springfield 16 were visited and but 1 had a pasteurizer and clarifier. In Worcester 35 were visited; 2 had pasteurizers and 2 others possessed clarifiers. Some few distributors produced milk under unusually good sanitary conditions, almost always keeping the bacterial count much lower than in ordinary milk. This they called "special" milk, and maintained that processing other than cooling and bottling was unnecessary and that pasteurizing was more likely to prove harmful than helpful to their trade. Under ordinary conditions the investment in processing machinery was very small indeed, and the labor involved in caring for the milk was confined to the most ordinary precautions to prevent souring.

DIFFICULTIES IN OBTAINING DATA.

Many difficulties were met in securing the necessary data to determine the cost of distribution. Very few producers or dealers kept proper books; in fact, any sort of bookkeeping was the exception rather than the rule. Complications also arose when the producer distributed the milk, for it was difficult to separate the items of production and distribution, the stable, shed, horse and harness being used for both. In many cases, therefore, estimates only could be given, but great care was taken that such estimates should cover the actual cost. The figures quoted are fairly accurate, and those on the cost of distribution of "special" milk can be relied upon in every detail, since most fortunately these distributors have kept accurate records for a period of several years.

Mixed Business. — The greatest problem, however, that confronted the investigators arose from the fact that in almost all cases the distributors not only deliver bottled milk directly to the individual consumer, but deliver wholesale milk both in bottles and in cases to other retailers and restaurants and also deliver cream both wholesale and retail. By good fortune figures were obtained from a dealer who kept accurate cost accounts and dealt entirely in wholesale milk. His accounts show that it cost him three-quarters of a cent ($0.0076) per quart to collect his milk from producers and distribute it in wholesale quantities. This figure is not applicable in most instances, however, for the reason that ordinarily the distributor does not go out of his way to deliver his wholesale milk; that is to say, his route is no longer and his apparent costs vary but little, whether he delivers retail milk only or adds a few wholesale deliveries. Careful thought indicates that an allowance of one-half cent per quart for wholesale milk delivered by a retail dealer covers the cost of this service in most instances; consequently this figure has been uniformly used.

This method of accounting, which very evidently lays the burden of costs on the retailed milk and rather arbitrarily establishes the costs of incidental wholesale distribution, is presented with full recognition of its weakness and its limitations. It does not mean that wholesale milk can be delivered at this cost, nor that a mixed business should not be considered on its merits; but it is manifestly unfair to assume that it costs as much to deliver 200 quarts at wholesale to two customers as to deliver 200 quarts at retail to 200 customers; and, since three-fourths of the quantity is retailed and nine-tenths of the equipment is for retailing, the arbitrary figures given are very reasonable interpretations of the facts.

The same question arises as to the delivery of retail cream. Based somewhat on the cost of delivering retail milk and estimating filling, capping, boxing and icing, loss of bottles and other contingent expenses, a charge of 3 cents per quart is deducted for its distribution. These deductions may be open to criticism but they were reached after making full investigations and obtaining the opinions of many distributors.

Analysis of Costs.

Cost data may be grouped under comparatively few heads: —

1. Investment in land, buildings, horses and all equipment that is more or less permanent in its nature.
2. Depreciation on buildings and equipment.
3. Maintenance of plant and equipment.
4. Circulating capital, *i.e.*, current operating supplies used but once — fuel, soap, ice, etc.; and "overhead," *i.e.*, fixed charges, rent, insurance, taxes, etc.
5. Labor.

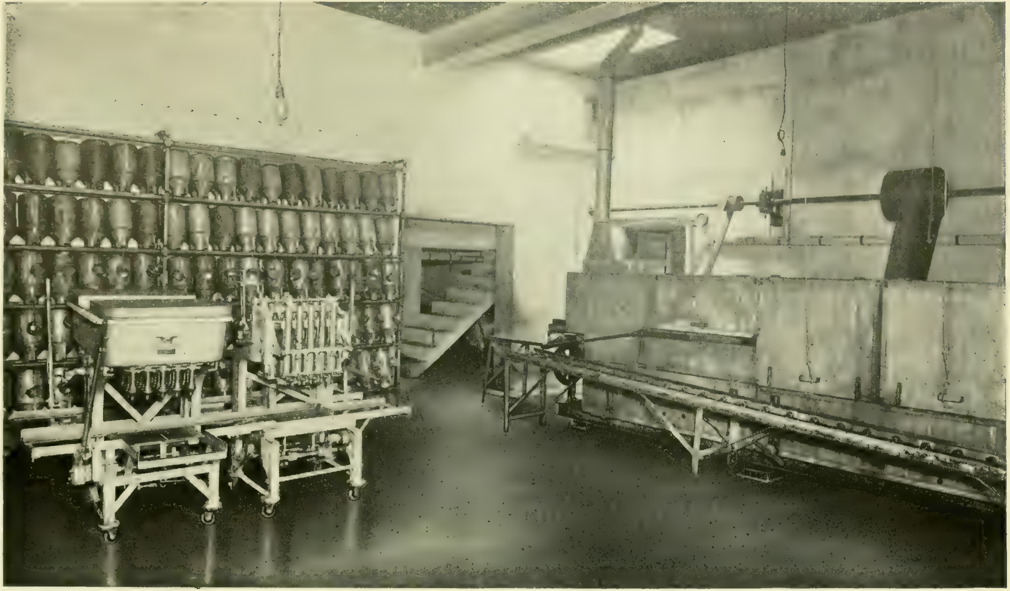
As previously noted these items may be assigned to processing, delivery and overhead or to processing and delivery.

Investment.

Investment includes the inventory value of real estate, horses and equipments used in the processing or delivery of milk and the housing of the horses and equipment. Depreciation was reckoned on all items of investment and was charged for one year. Some specific problems may be mentioned.

Depreciation Problems.

Horses. — No hard and fast rule was followed in determining the depreciation of horses. It was asserted by many that a horse worth $300 after giving ten years' service could be sold for $100; after five years' service, for $200, thus giving an annual depreciation in each case of $20. Some distributors affirmed that no depreciation of horse flesh could honestly be



The processing equipment of a progressive distributor.

charged, since they usually disposed of their horses after three or four years for more than they cost. Other animals eighteen and twenty years of age were giving good service.

Rate of Depreciation. — For these reasons each individual case was dealt with on its merits under this general formula: first cost of animal, less the selling price or the present worth, divided by number of years of service equals the annual depreciation. This method of calculation takes no account of losses by death; only horses now in service are considered. Where such losses had occurred in recent years some allowance was made, however. The figures obtained show that the depreciation of horse flesh increased in proportion to the size of the town or city, and also of the load hauled. In Amherst and Walpole annual horse depreciation averaged 7.5 per cent. In Worcester the average was 9.5 per cent.

Buildings. — To compute the investment in buildings and the necessary allowance for depreciation was also a source of some difficulty. In Walpole and Worcester a number of dairies were housed in basements, some in basements of residences. Moreover, the majority of the country dairies visited are in the barn, stable or shed, a partitioned space in these buildings being all that is considered necessary for the plant. In all these instances an estimate was made of the value of the whole building; this was multiplied by the fractional space occupied by the milk plant and to this was added the outlay for fitting up the plant itself. When the valuation was arrived at, 3 per cent., as a rule, was charged off for depreciation; 2 per cent. for taxes and insurance; and 5 per cent. for interest. This may be a trifle high, but in some cases the actual charges for taxes and insurance were more than 2 per cent.

Equipment. — The equipment varied exceedingly, but without exception fairly reliable data were obtained. No arbitrary rule was followed in computing the depreciation, since each individual item has a different period of service and these periods vary with the different plants and users. Many distributors had experience sufficient to enable the investigator to arrive at a fairly exact figure; in other plants estimates were necessary. In a number of cases the equipment was very meager and the methods employed crude; filling bottles by hand, heating water over a small gas burner, and washing bottles by hand were not unusual. Except in the case of the large dealers in the cities and a few of the more progressive producers who distribute, live steam was not used for washing or sterilizing and in several cases the heating apparatus was entirely inadequate.

Harness. — The almost unanimous opinion was that the life of a set of harness costing from $35 to $40 is five years, provided it is kept in good repair; the repairs usually amount to $5 a year. This bears out the statement of harness makers that harness costs $1 a month.

Wagons and Sleighs. — There was very little difference of opinion regarding the upkeep and life of wagons and pungs. The price of wagons ranged from $175 to $275, with a life of approximately eight years. They are usually varnished every year and painted and overhauled every alternate year. Pungs or sleighs cost an average of $50 and last about fifteen years, very little being spent on upkeep.

Other Equipment. — Boxes worth 80 cents to $1.25 are good for five years. There is a difference of opinion as to the relative merits of the wooden and the steel boxes. Five complete sets of cans are necessary for the average dealer, one set being replaced each year. This item, however, should be charged to transportation except in the case of the delivery of wholesale milk.

Maintenance.

Maintenance includes the expenditure necessary for the repair and upkeep of the buildings and equipment, including feed of horses and the loss of bottles and cans. In general, the outlay necessary to maintain the plant in working order is maintenance. Such items as grease and oil, veterinary service, shoeing, stable sundries, brushes, brooms, blankets, feed bags, carriers, hose, medicine, paint and other sundries required to keep up the buildings and equipment fall under this head.

Working Capital.

Working capital (or overhead and current supplies) includes such items as soap, ice, light, fuel, stationery, telephone, rent, insurance, taxes, interest on investment, spoilage, surplus, shrinkage and bad bills. It was difficult in many cases to separate these items, spoilage and surplus being included by some in shrinkage and by others in bad bills; fuel was consumed for other purposes than the dairy; the telephone included private use; and insurance, taxes and water rates often covered the residence or buildings used for other purposes in addition to the dairy. Assessed values and tax rates vary greatly, but in general 2 per cent. of the actual value was allocated to taxes and insurance. Insurance averaged about 1½ per cent. for three years. Interest was uniformly computed at 5 per cent. on the entire investment.

Labor.

Labor is classified as hired, home and personal. *Home labor* is labor provided by members of the family, such as assistance in the dairy or on the milk wagon, but more often in keeping the books. Usually home labor does not represent an expenditure, but is charged at the prevailing rates. *Personal labor* is the labor of the proprietor himself and is valued at his own estimate, never less than 25 cents per hour. In no case was the accepted estimate considered excessive or below a reasonable remuneration.

There is much individual variation in each of these items, especially among the producers who board the hired help. The wages paid varied from $25 to $35 per month and board; the estimates for board vary from $15 to $30 per month. The time, too, must often be distributed more or less unequally and arbitrarily between farm work and the preparation and delivery of milk. In all instances these adjustments were made carefully, but except as averages they cannot be considered in all respects infallible.

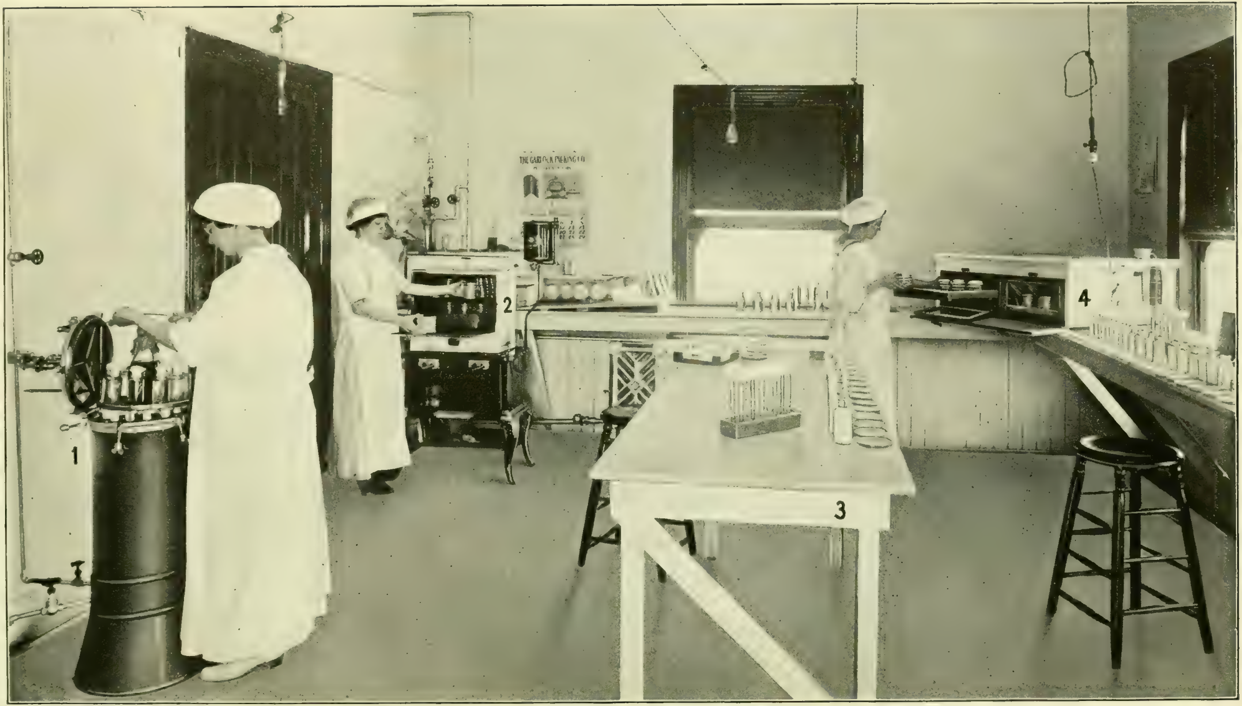
TABLE IV. — *Summary of Total Costs, and Cost per 1,000 Quarts, of distributing Milk and Cream (Forty-two Plants).*

	VALUE OF —																				TOTAL.	
	Horses.	Milk Sheds.	Ice Houses.	Stables.	Boilers.	Pumps.	Tanks.	Washers.	Fillers.	Pasteurizers.	Clarifiers.	Separators.	Ice Chests.	Harnesses.	Wagons.	Pungs.	Boxes.	Cans.	Office.	Sundries.	Per 1,000 Quarts.	Amount.
Investment: —																						
Total,	$37,913 00	$26,002 00	$7,320 00	$24,333 34	$7,743 92	$1,560 00	$220 00	$4,755 00	$5,508 00	$4,340 00	$1,240 00	$410 00	$2,523 50	$6,121 00	$25,871 00	$6,781 00	$2,997 55	$2,629 70	$1,340 00	$545 00	–	$170,154 01
Per 1,000 quarts,	3 07	2 16	61	–	–	–	–	–	–	–	–	–	–	51	2 15	56	25	22	–	–	$14 15	–
Depreciation: —																						
Total,	$3,971 71	$780 06	$359 60	$730 00	$764 58	$150 00	$16 00	$481 00	$509 73	$407 33	$116 00	$41 00	$203 73	$1,372 93	$3,787 85	$397 56	$676 82	$376 29	$132 00	$64 50	–	$15,338 69
Per 1,000 quarts,	33	06	03	–	–	–	–	–	–	–	–	–	–	11	31	03	05	03	–	–	$1 28	–
	Repairs.	Sundries.	Shoeing.	Feed.	Carriers.	Bottles.	Cans.															
Maintenance: —																						
Total,	$6,896 31	$3,788 34	$4,193 80	$31,773 52	$184 67	$7,566 92	$493 85	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	–	54,897 41
Per 1,000 quarts,	58	31	35	2 64	02	63	04	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	4 56	–
	Rent.	Soap.	Caps.	Ice.	Light and Oil.	Fuel.	Stationery.	Insurance and Taxes.	Interest.	Spoilage and Shrinkage.	Bad Bills.	Sundries.										
Circulating capital: —																						
Total,	$3,324 00	$1,122 07	$2,519 19	$7,376 45	$1,578 30	$3,872 60	$1,934 45	$3,288 72	$8,326 21	$2,938 70	$6,560 52	$3,227 74	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	–	46,068 95
Per 1,000 quarts,	28	09	21	61	13	32	16	27	69	24	55	27	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	3 83	–
Labor: —																						
Total,	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	–	153,597 45
Per 1,000 quarts,	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	12 77	–
																					$22 44	$269,902 50

MILK DISTRIBUTED.

Retail: —	
Daily (quarts),	24,421.70
Yearly (quarts),	8,913,925 00
Wholesale: —	
Yearly (quarts),	2,890,595 00
Cream: —	
Yearly (quarts),	222,344 00
Total yearly cost of retail distribution,	$248,809 39
Cost per quart retail distribution (cents),	2.79

Miles travelled daily, retail,	834
Cost per mile (cents), retail,	81
Quarts per mile daily, retail,	29 20
Quarts per customer daily, retail,	1 18
Quarts per horse daily, retail,	174 40
Miles per customer, retail,	.04
Customers: —	
Wholesale,	498
Retail,	20,674



Laboratory for either City or Country.

1. Steam heater for preparing agar. 2. Sterilizer. 3. Table for preparing samples to plate. 4. Incubator. (Courtesy of Boston Chamber of Commerce.)

Costs of Processing and Delivering summarized.

Table IV is an itemized summary of costs tabulated for 42 plants in Springfield and Worcester. Facts obtained in these cities are fairly comparable and the conclusions are quite as satisfactory as if the data for all six localities were included in the tabulations. The summary represents an annual business of approximately 9,000,000 quarts of retail milk, 3,000,000 quarts of wholesale milk and 222,000 quarts of cream out of a total distribution of about 15,000,000 quarts of retail milk, 4,700,000 quarts of wholesale milk and 300,000 quarts of cream — or about 60 per cent. of the total deliveries considered in this investigation. The milk of these 42 distributors was delivered to about 21,000 customers.

The total *investment* in plants and equipments amounts to about 1½ cents per quart of milk delivered. The largest investment items are milk sheds, horses and stables; boilers and ice houses come next but are comparatively insignificant.

The chief items of *depreciation* apply to horses, wagons and harness. These account for three-fifths of the total depreciation; another fifth is assigned to milk shed, stable, boxes, cans and boiler. By ascertaining the first cost, the present value and the time used, most of the items of depreciation are easily calculated.

Nearly $55,000 is classified under *maintenance*. More than three-fifths of this is for horse feed and just about 80 per cent. is for feed, repairs and horseshoeing. Lost bottles and cans are classified as maintenance and make up most of the remainder.

Circulating or working capital is here used to include overhead and fixed charges and supplies which are destroyed in one using. The largest item is interest on the investment, computed at 5 per cent.; the second is ice; and the third is bad bills. These items, with rent, insurance and taxes, fuel and loss by spoilage and shrinkage, account for 75 per cent. of this charge. Other items are soap, caps, stationery, light and oil. Labor of all kinds is by far the largest item, amounting to nearly three-fifths of the entire cost, or one and three-fifths cents per quart of milk retailed.

The average cost of processing and retailing milk is 2.79 cents per quart for an average daily delivery of 175 quarts of retailed milk per horse the year round. This cost is arrived at by deducting from the total expenses one-half cent a quart for the wholesale milk distributed and 3 cents a quart for retail cream.

TABLE V. — *Cost per Quart and Percentage of Total Cost for Depreciation, Maintenance, Circulating Capital and Labor.*

	Cost per Quart (Cents).	Percentage.
Depreciation,	.16	5.69
Maintenance,	.57	20.34
Circulating capital,	.48	17.06
Labor,	1.58	56.91
	2.79	100.00
Preparation,	.758	27.19
Delivery,	1.528	55.14
Overhead,	.492	17.67
	2.79	100.00

COSTS CLASSIFIED BY SIZE AND KIND OF BUSINESS.

Perhaps a better analysis of 80 plants is presented in Table VI. In this analysis an attempt has been made to classify the distributors by size of business and to set forth the items of cost under processing, delivery and overhead.

Only three plants do a business exceeding 2,000 quarts daily, hence the figures for these must be used with caution. Sixty plants do a mixed business, about three-fourths retail and one-fourth wholesale. Twenty plants deliver retail milk only. None of the all-retail plants do a daily business of 500 quarts. They are of one and two wagon capacity and so far as size of business is concerned should be classified with the "under 500" group.

The actual per quart costs, which include both *wholesale and retail* milk, run from about 1.6 to 2.9 cents per quart. The discrepancy between per quart costs given in Tables IV, V and VI is accounted for by the fact that in Table IV only 42 firms are considered and the cost of distributing all wholesale milk is computed at one-half cent per quart.

Plants of 500 to 1,000 quarts capacity do business most economically — 1.64 cents a quart for *all* milk delivered and 2.05 cents per quart for milk retailed. These costs are 25 per cent. and 22 per cent., respectively, below the average of all the plants investigated (2.21 cents for all deliveries and 2.64 cents for retailed milk). Plants of 1,000 to 2,000 quarts distribute for 1.82 and 2.23 cents per quart. The 27 plants of less than 500 quarts daily capacity average 2.04 and 2.66 cents a quart. The 3 plants doing a mixed business of more than 2,000 quarts daily and the 20 exclusively retail plants show the highest per quart costs for retailing — 2.92 and 2.93 cents for all expenses.

The overhead expense is the smallest item and in reality should be distributed between processing and delivery. It varies from 12.3 to 18.9 per cent. of the total cost in mixed, and 14.7 per cent. in retail business. This item seems to vary directly with the size of the business, *i.e.*, with the quantity handled. The processing expense runs from 24.7 to 31.8 per cent. of the total. In general this expense varies inversely with the quantity handled. Delivery costs a little more than one-half of the total, running rather uniformly around 55 per cent. The 1,000 to 2,000 quart group averaged 57.7 per cent. for delivery but the individual variations are wide. On the whole the figures show comparatively little correlation between costs and size of business.

Investment and Size of Business.

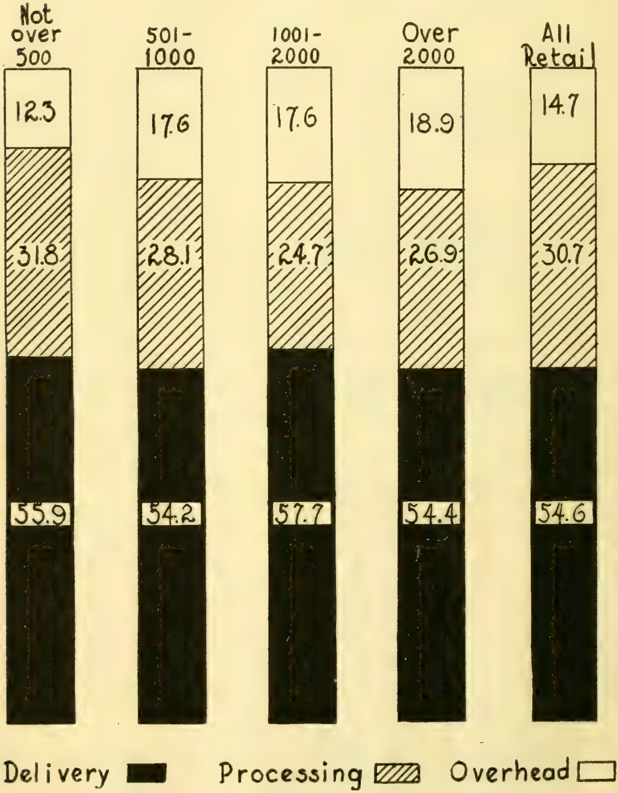
The relation between size of business and average total amount invested in plant and equipment is of interest. The tabulations in Table VII., as might be expected, show a consistent correlation between investment and size of business. But when the investment per 1,000 quarts of milk distributed is considered, this consistent correlation is not shown. The strikingly high investment ($22.61 per 1,000 quarts) of the retail dealers is, perhaps, rather surprising when compared with an investment of $4.30 per 1,000 quarts in plants during a mixed business of the same size. Enterprises of the second and fourth classes have also a very high investment ratio. One might suppose that a milk-distributing plant could increase its volume of business by corresponding increase in plant, but an increase from an average of 360 quarts per day to an average of 710 quarts a day seems to multiply the total investment nearly six times, whereas men who do a retail business exclusively have four times the total investment of those who do a mixed business of the same size.

TABLE VI. — *Summary Statement of Expenses of Handling and Distributing Market Milk (Eighty Plants). Average Investments, Amounts handled and Items of Expenses classified in Groups.*

	SIZE OR KIND OF BUSINESS.									
Number of quarts sold daily,	Under 500.		500–1,000.		1,000–2,000.		Over 2,000.		All Retail.	
Number of establishments in each group,	27		20		10		3		20	
	Annually.	Daily.	Annually.	Daily.	Annually.	Daily.	Annually.	Daily.	Annually.	Daily.
Average number of quarts { Wholesale,	37,423	103	67,803	186	131,021	365	188,583	517	–	–
Average number of quarts { Retail,	94,125	257	191,067	523	422,912	1,159	879,163	2,409	100,664	276
										Weighted Average
PROCESSING INVESTMENT (AVERAGE PER PLANT),	$453 88		$836 89		$1,423 85		$11,756 67		$784 05	
Preparation expenses: —										
Depreciation and maintenance,	69 78		103 35		362 29		1,122 06		171 92	
Supplies,	283 64		415 92		982 49		1,026 96		315 19	
Labor,	506 14		677 83		1,174 06		5,062 67		423 74	
Average total cost for preparation,	859 56		1,197 10		2,518 84		7,211 68		910 84	.0064
Cost per quart,	.0065		.0046		.0045		.0067		.0090	
DELIVERY OR DISTRIBUTION INVESTMENT,	$112 10		$2,488 00		$3,855 05		$8,837 00		$1,492 94	
Delivery expenses: —										
Depreciation and maintenance,	222 86		414 10		730 26		1,851 75		310 85	
Supplies,	386 71		650 48		1,521 01		3,654 65		387 92	
Labor,	897 63		1,253 08		3,580 65		8,942 30		912 95	
Average total cost for delivery,	1,507 20		2,317 66		5,831 92		14,448 70		1,611 71	.01214
Cost per quart,	.0114		.0089		.0105		.0135		.0160	

OVERHEAD INVESTMENT,	-	-	-	-	-	
Overhead expenses: —						
Administration and clerical salaries,	$163 13	$325 48	$844 35	$1,445 33	$164 07	
Light, telephone, stationery, etc.,	45 40	48 44	104 36	325 67	40 08	
Insurance, taxes, license,	15 15	38 80	210 93	630 62	28 85	
Shrinkage and spoilage,	23 08	61 65	100 85	992 67	38 30	
Bad accounts,	52 84	117 59	226 77	621 67	48 80	
Interest,	28 30	166 24	263 95	1,029 68	113 85	
Average total cost for overhead,	327 90	758 20	1,751 21	5,045 64	433 94	.0032
Cost per quart,	.0025	.0029	.0032	.0047	.0043	
Average total costs for preparation, delivery and overhead charges,	$2,694 66	$4,272 95	$10,101 97	$26,706 03	$2,956 49	-
Total costs per quart for preparation, delivery and overhead charges,	.0204	.0164	.0182	.0249	.0293	.0218
Total costs per quart for *retail* delivery, allowing .5 cent per quart for milk delivered at wholesale,	.0266	.0205	.0223	.0292	.0293	.0254

PERCENTAGES OF TOTAL COSTS PER QUART BY SIZE OF TOTAL BUSINESS



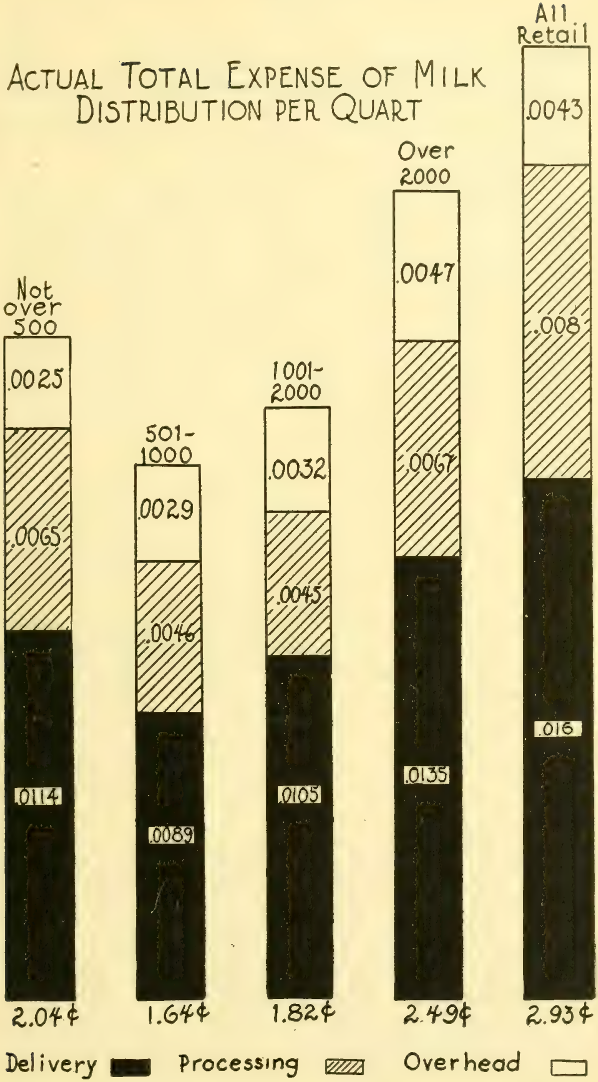

ACTUAL TOTAL EXPENSE OF MILK DISTRIBUTION PER QUART
Not over 500
.0025
.0065
.0114
2.04¢
501-1000
.0029
.0046
.0089
1.64¢
1001-2000
.0032
.0045
.0105
1.82¢
Over 2000
.0047
.0067
.0135
2.49¢
All Retail
.0043
.008
.016
2.93¢
Delivery
Processing
Overhead

TABLE VII. — *Percentages of Total Cost per Quart of Wholesale and Retail Milk (80 Plants), by Size or Character of Business.*

	I Under 500 Quarts.	II 500-1,000 Quarts.	III 1,001-2,000 Quarts.	IV Over 2,000 Quarts.	V All Retail.	Average.
Number of establishments, .	27	20	10	3	20	-
Total cost, ...	$0 0204	$0 0164	$0 0182	$0 0249	$0 0293	$0 0218
Per cent., ...	100	100	100	100	100	100
Processing expense, . . .	$0 0065	$0 0046	$0 0045	$0 0067	$0 0090	$0 0064
Per cent., ...	31.8	28.1	24.7	26.9	30.7	29.3
Delivery expense, . . .	$0 0114	$0 0089	$0 0105	$0 0135	$0 0160	$0 01214
Per cent., ...	55.9	54.2	57.7	54.2	54.6	55.7
Overhead expense, . . .	$0 0025	$0 0029	$0 0032	$0 0047	$0 0043	$0 00322
Per cent., ...	12.3	17.6	17.6	18.9	14.7	15.0
Investment: —						
Per plant, ...	$566	$3,325	$5,279	$20,594	$2,277	-
Per 1,000 quarts milk sold, .	4 30	12 84	9 51	19 30	22 61	-

PERCENTAGE ANALYSIS OF COSTS.

The cost analysis presented in Table VIII shows the importance of labor both in processing and delivery, although the percentual importance varies greatly with the size of the business. The labor item differs also in the major processes of distribution. The relative importance of the labor item in the fourth group is the striking feature — 70 per cent. of the *processing expense* as contrasted with a maximum of 59 per cent. and a minimum of 46½ per cent. in the other groups. The labor factor in *delivery costs* is more uniform but even here the labor item in the fourth group reaches the maximum — 61.9 per cent.

It is significant that the labor item in *preparation* is lowest in the third and the all-retail groups, although the third group shows an actual processing cost of .45 cents, and the all-retail a cost of .90 cents per quart.

The principal point of emphasis in the overhead analysis, aside from the notable variation in the importance of the various items, is the high percentage of shrinkage and spoilage in the "over 2,000" group. Bad accounts average more than one-eighth of the overhead and, curiously enough, are percentually highest in Groups I and II, which show the lowest actual overhead. The interest item, of course, varies with the investment. Its percentual importance averages from about 9 per cent. in Group I, to 26.3 per cent. (three times as much) in the all-retail group.

TABLE VIII. — *Percentages of Costs in Relation to Size of Business. Amounts handled and Items of Expenses classified in Groups.*

	Percentages according to Size or Kind of Business.				
	I	II	III	IV	V
Number of quarts sold daily,	Under 500.	500-1,000.	1,001-2,000.	Over 2,000.	All Retail.
Number of establishments,	27	20	10	3	20
Average per cent. quarts sold daily: —					
Wholesale,	28.4	26.1	23.6	17.6	-
Retail,	71.6	73.9	76.4	82.4	100.0
Preparation expenses in per cent. of total.	31.8	28.1	24.7	26.9	30.7
Depreciation and maintenance,	8.1	8.6	14.3	15.6	18.9
Supplies,	33.0	34.7	39.1	14.2	34.6
Labor,	58.9	56.6	46.6	70.2	46.5
Delivery expenses in per cent. of total,	55.9	54.2	57.7	54.2	54.6
Depreciation and maintenance,	14.8	17.8	12.5	12.8	19.3
Supplies,	25.7	28.1	26.1	25.3	24.1
Labor,	59.5	54.1	61.4	61.9	56.6
Overhead expenses in per cent. of total,	12.3	17.6	17.6	18.9	14.7
Administrative and clerical salaries,	49.8	43.0	48.2	28.6	37.8
Light, telephone, stationery,	13.8	6.4	6.0	6.5	9.2
Insurance, taxes, license,	4.6	5.1	12.0	12.5	6.6
Shrinkage and spoilage,	7.0	8.1	5.8	19.7	8.8
Bad accounts,	16.1	15.5	13.0	12.3	11.3
Interest,	8.7	21.9	15.0	20.4	26.3
Expenses in per cent. of receipts: —					
Preparation or processing,	7.9	5.8	5.0	8.4	9.4
Delivery,	13.9	11.1	11.6	17.0	16.7
Overhead,	2.9	3.4	3.3	5.7	4.3
Total expenses in per cent. of receipts,	24.7	20.3	19.9	31.1	30.4

The relation of costs to receipts is the really significant fact to the distributor. Costs run from a minimum of 19.9 per cent. to a maximum of 31.1 per cent. of total receipts. This means that the costs of the all-retail and "over 2,000" groups, for example, absorb 30 to 31 per cent. of the total receipts, a portion more than 50 per cent. greater than the part taken by the second and third groups.

This percentage which the expenses bear to receipts may be called the operating ratio. It is lowest in Groups II and III and highest in Group IV. The lower the ratio the more economical the operation of the plant. The operating ratio in any business is very significant. In milk distribution 20 per cent. is probably a low ratio and 30 per cent. a high ratio, but much more accounting must be done to determine this. In all instances the more expensive distribution is due both to higher processing and higher delivery costs and, in the fourth and all-retail groups also to higher overhead expenses.

Comparative Costs by Localities.

Table IX presents comparative cost data by towns. In these figures no attempt has been made to separate costs into processing and delivery. All the firms operating in Amherst and Walpole are in the "500 quarts or under" class; all but three of the Haverhill and Pittsfield firms are distributing less than 1,000 quarts per day; hence the firms interviewed doing a daily business of 1,000 quarts and more are almost all in Springfield and Worcester.

The data show plainly the greater cost per quart in the two larger cities, a cost which is seen in practically all items entering into distribution. Few conclusions of significance as regards variations by localities can be drawn from the figures giving total locality costs.

TABLE IX. — *Comparative Investment, Costs, Quantities and Customers served in Six Towns and Cities (Eighty-six Distributors)*

CITY OR TOWN.	INVESTMENT.					DEPRECIATION.			
	HORSES.		Buildings.	Equipment.	Total.	Horses.	Buildings.	Equipment.	Total.
	Value.	Number.							
Amherst,	$1,200 00	6	$2,210 00	$1,932 00	$5,342 00	$104 16	$214 33	$243 24	$561 73
Walpole,	2,320 00	9	8,600 00	1,900 20	12,820 20	161 07	223 00	232 33	616 40
Haverhill,	10,844 00	48	21,591 66	19,262 92	51,698 58	1,315 40	610 65	2,450 19	4,376 24
Pittsfield,	9,600 00	39	9,840 00	11,690 15	31,130 15	937 69	306 20	1,777 31	3,021 20
Springfield,	11,350 00	47	19,732 00	27,282 65	58,364 65	1,445 71	594 96	3,579 04	5,619 71
Worcester,	26,563 00	100	37,823 34	47,403 02	111,789 36	2,526 00	1,274 70	5,918 28	9,718 98

TABLE IX. — *Comparative Investment, Costs, Quantities and Customers served in Six Towns and Cities (Eighty-six Distributors)* — Con.

CITY OR TOWN.	Maintenance.	Circulating Capital.	LABOR.				Total Cost.	Number of Dealers.
			Hired.	Home.	Personal.	Total.		
Amherst,	$1,141 22	$1,068 48	$3,491 02	$471 32	$1,635 08	$5,597 42	$8,368 85	5
Walpole,	2,291 22	2,262 37	-	-	-	5,827 69	10,907 68	5
Haverhill,	15,773 94	14,344 24	15,688 75	2,209 30	17,678 57	35,576 62	70,071 04	22
Pittsfield,	10,334 85	9,131 62	15,656 41	733 18	12,542 09	28,931 68	51,419 34	12
Springfield,	19,543 48	16,587 05	49,491 55	-	12,717 47	62,209 02	103,959 26	10
Worcester,	35,353 93	29,481 98	53,408 96	6,525 70	31,453 77	91,388 43	165,943 32	32

TABLE IX. — *Comparative Investment, Costs, Quantities and Customers served in Six Towns and Cities (Eighty-six Distributors)* — Con.

CITY OR TOWN.	MILK AND CREAM DISTRIBUTED.				YEARLY COST OF DISTRIBUTION.		RETAIL.		
	RETAIL MILK.		WHOLESALE MILK.	CREAM.	Retail Cost.	Cost per Quart (Cents.)	Quarts per Horse.	Quarts per Mile.	Quarts per Customer.
	Daily (Quarts).	Yearly (Quarts).	Yearly (Quarts).	Yearly (Quarts).					
Amherst,	1,050.0	383,250	87,600	10,950	$7,775 73	2.03	175.0	17.9	1.235
Walpole,	1,289.0	470,485	29,200	13,140	10,643 68	2.26	143 2	23.8	1.025
Haverhill,	8,232.0	3,004,680	925,000	22,565	64,769 09	2.16	176.3	21.4	1.299
Pittsfield,	5,508.7	2,010,675	759,200	37,139	46,609 17	2.31	141.2	21.6	1.276
Springfield,	8,612.7	3,143,640	367,350	193,515	96,297 36	3.06	183.2	37.9	1.106
Worcester,	15,809.0	5,770,285	2,523,245	28,829	152,512 03	2.64	170.0	28.0	1.227
	40,501.4	14,783,015	4,691,595	306,138	$378,607 06	2.56	-	-	-

TABLE IX. — *Comparative Investment, Costs, Quantities and Customers served in Six Towns and Cities (Eighty-six Distributors)* — Con.

CITY OR TOWN.	MILES TRAVELED.		Cost per Mile.	CUSTOMERS SERVED.			SELLING PRICE OF MILK.		COST PRICE OF MILK.		Number of Routes.	Miles per Retail Route.
	Daily.	Per Customer.		Retail.	Wholesale.	Per Mile.	Wholesale.	Retail.	Collected.	Delivered.		
Amherst,	58.5	.068	$0 36	850	7	14.6	$0 0700	$0 08	-	$0 050	6	9.7
Walpole,	54.0	.042	54	1,257	4	23.3	0700	09	-	055	7	7.7
Haverhill,	395.0	.060	44	6,513	88	16.7	0700	08	$0 050	055	35	11.3
Pittsfield,	254.0	.058	50	4,317	69	17.2	0600	08	045	050	23	10.9
Springfield,	227.0	.029	1 16	7,784	95	34.7	0750	09	045	050	33	7.2
Worcester,	565.0	.042	74	12,890	403	23.5	0625	08	045	050	63	8.2

The comparative analysis of costs, including both processing and delivery, of retailing milk by cities and towns is exhibited in Table X. Before comparing localities it may be well to note that by far the most important item is labor, which varies from one-half to more than two-thirds of the whole distributing cost. This includes only man labor, horse labor being carried in the other items. This expense is greatest in Springfield, where it amounts to nearly 2 cents a quart, and lowest in Haverhill, where it is scarcely more than 1 cent.

Depreciation is the smallest charge, and runs about 6 per cent. of the total; actually it is lowest in Haverhill and highest in Springfield.

Maintenance and circulating capital show great relative variation. Both are relatively and actually lowest in Amherst and actually highest in Worcester and Springfield. The two charges amount to .52 cents a quart in Amherst, .85 in Walpole, .88 in Pittsfield, .92 in Haverhill, 1.03 cents in Worcester and 1.04 cents in Springfield. In general these items increase with the size of the town.

Amherst v. Walpole.

Amherst seems to process and distribute its supply of milk more economically than Walpole, notwithstanding the labor bill is slightly higher. Omitting cream, our figures show in round numbers 500,000 quarts of wholesale and retail milk delivered yearly in Walpole and 471,000 in Amherst. On this basis, Walpole's labor costs $11.65 per 1,000 quarts, and Amherst's $11.87; for retailed milk the labor expense is $12.58 per 1,000 quarts in Walpole and $13.69 in Amherst. Hired help is a little cheaper and more plentiful in the eastern part of the State, though the personal labor in both towns was computed at 25 cents per hour. The time occupied in delivery is the same, though the average milk route in Walpole is 25 per cent. shorter. Walpole serves more customers per wagon, 180 to 143 for Amherst, but delivers less milk per customer.

The dealers in Amherst, however, expend less for maintenance and working capital. The lower maintenance is due in part to the greater load per horse, the average retail load per horse being 175 quarts, in contrast with 143 quarts in Walpole. It must be noted, however, that Walpole hauls more per wagon — including wholesale milk and cream, 234 quarts to 214 for Amherst; the explanation is a two-horse wagon. In working capital there is a margin of .19 cents per quart (43 per cent. less) in favor of Amherst. Table X shows that these two items amount to nearly 40 per cent. of the total in Walpole as compared with less than 26 per cent. in Amherst.

With the exception of the items *stationery* and *shrinkage*, the Amherst figures for circulating capital show a big saving. The greater stationery charge is accounted for by the use of tickets by several of the Amherst dealers. The wisdom of this expenditure is justified by the small loss in bottles and a minimum loss by bad debts. It cost the five Walpole dealers $340 a year for bottles, or 72 cents per 1,000 quarts of retail milk delivered.

TABLE X. — *Comparative Distribution and Analysis of Costs per Quart of Retail Milk distributed, absolutely and by Percentages (Six Cities and Towns).*

	AMHERST.		WALPOLE.		HAVERHILL.		PITTSFIELD.		SPRINGFIELD.		WORCESTER.	
	Per Cent.	Cost per Quart.	Per Cent.	Cost per Quart.	Per Cent.	Cost per Quart.	Per Cent.	Cost per Quart.	Per Cent.	Cost per Quart.	Per Cent.	Cost per Quart.
Depreciation,	6.68	$0 00136	6.57	$0 00148	6.29	$0 00139	5.87	$0 00136	5.42	$0 00166	5.87	$0 00155
Maintenance,	13.66	00278	18.45	00417	22.73	00487	20.09	00465	18.10	00554	21.25	00561
Circulating capital,	12.18	00247	20.97	00438	20.60	00448	17.75	00412	15.96	00488	17.77	00469
Labor,	67.48	01369	54.01	01258	50.38	01086	56.29	01307	60.52	01852	55.11	01455
Totals,	100.00	$0 02030	100.00	$0 02260	100.00	$0 02160	100.00	$0 02320	100.00	$0 03060	100.00	$0 02640

Five Amherst dealers expend $140.69 for bottles, or 37 cents per 1,000 quarts of retail milk; this includes one dealer who does not use tickets. Eliminating this dealer for the sake of accurate comparison, the results may be presented in tabular form, as follows: —

DEALERS IN —	Number.	Distribute 1,000 Quarts.	EXPEND FOR BOTTLES.		BAD DEBTS.	
			Total.	Per 1,000 Quarts.	Total.	Per 1,000 Quarts.
Walpole, ...	5	470.5	$340 00	$0 72	$182	$0 40
Amherst using tickets, . .	4	346.7	133 40	38	31	09

It is significant that of $82 reported as lost through bad debts by Amherst distributors, $51 were reported by one dealer who did not use the ticket system. Comparing the figures of Amherst and Walpole dealers who do and who do not use tickets, it appears that where five Walpole dealers using no tickets suffer by bad debts a loss of 40 cents per 1,000 quarts of milk sold at retail, and one Amherst dealer loses similarly 62 cents, the four Amherst distributors using tickets have but 9 cents of bad debts for each 1,000 quarts retailed.

Under the ticket system the cost of collection is somewhat less, but since the drivers do the collecting it is difficult to approximate this difference. Tickets, of course, mean cash in advance; just how long in advance depends on the price of milk, and the amount used per family, since tickets are usually sold in $1 strips. The price per quart is exactly the same, whether the customer buys tickets in advance or pays in currency when the milk is delivered.

Ice cost Walpole dealers $1 per 1,000 quarts ($0.001 per quart) of milk, and the Amherst dealers 80 cents per 1,000 quarts ($0.0008 per quart).

Haverhill v. Pittsfield.

The difference in the figures for these towns is not marked. Pittsfield expends a very little less per quart for maintenance and circulating capital, but this is more than offset by higher labor costs. Labor is comparatively expensive, due to the competition of the summer homes in the vicinity.

Although Haverhill distributed milk at a lower cost per quart than any of the four cities, it was not at the expense of service, but rather as the result of the low labor cost coupled with the number of quarts delivered per horse, in other words, by getting the best service out of the horse. Haverhill averages 176.3 *retail* quarts per day per horse, while Pittsfield averages but 141.2 quarts per horse. Moreover, Pittsfield distributors deliver more cream and wholesale milk per route to a smaller number of customers than do Haverhill milkmen — about 100 quarts as against 75 for Haverhill.

It may be said in passing that the milk supplied by Haverhill dealers is exceptionally pure and clean. These qualities are popularly supposed to be expensive. If they are, Haverhill dealers have met the increased cost by economies elsewhere. The city's entire supply comes from local producers. Thus any impure milk can be at once traced to the source of supply and the producer of exceptionally clean milk be quickly recognized. Frequent inspections and monthly tests by a competent bacteriologist are made. The methods of inspection and the publication of the results of the monthly bacterial analyses have educated the Haverhill public to appreciate the value of clean milk and have stimulated a healthy rivalry among the producers and distributors. Only one dealer uses a pasteurizer and he is the only distributor who purchases milk outside an 8-mile radius.

Springfield v. Worcester.

It costs the Springfield dealers studied 16 per cent. more than Worcester dealers to distribute retail milk; and 25 per cent. more than the average of all dealers investigated. Except in the amount spent for maintenance, all the costs of distribution are lower in Worcester than in Springfield. As a matter of fact, differences in depreciation, maintenance and overhead are negligible. The labor item alone requires attention. Worcester has cheaper labor because a large proportion of the distributors are producers, and farm labor at $50 a month (cost of board included) is much lower than labor in the city. In addition to this, a fair proportion of Worcester's milk supply is distributed by foreign-born dealers who value their services cheaply.

A short time ago an ordinance was passed doing away with basement dairies in Springfield. This has been productive of much good, although it entails considerable expense. Depreciation has naturally increased in this city but without a corresponding increase in maintenance.

TABLE XI. — *A Detailed Comparative Study of Distribution Costs of Four Producing Distributors and Five Dealers.*

(A) PRODUCERS.

Investment.

PRODUCER'S NUMBER.	HORSES.		Milk Shed.	Ice House.	Stable.	Boiler.	Filler.	Ice Chest.	Harness.	Wagons.	Boxes.	Cans.	Total.
	Number.	Value.											
9, ...	3	$900 00	-	-	-	$150 00	$10 00	$100 00	$75 00	$350 00	$25 00	$8 00	$1,618 00
12, ...	3	800 00	$500 00	$300 00	$1,000 00	100 00	30 00	-	150 00	610 00	62 50	62 50	3,615 00
18, ...	3	800 00	100 00	200 00	-	275 00	72 00	-	70 00	650 00	37 50	-	2,204 50
23, ...	1	150 00	20 00	100 00	-	225 00	40 00	-	18 00	251 00	15 50	17 00	836 50
Total, . .	10	$2,650 00	$620 00	$600 00	$1,000 00	$750 00	$152 00	$100 00	$313 00	$1,861 00	$140 50	$87 50	$8,274 00

Depreciation.

9, ...	3	$60 00	-	-	-	$15 00	$2 00	$10 00	$25 00	$37 38	$5 00	$2 00	$156 38
12, ...	3	71 43	$15 00	$9 00	$30 00	10 00	3 50	-	30 00	75 38	7 82	-	252 13
18, ...	3	100 00	3 00	6 00	-	27 50	7 20	-	14 00	60 00	4 69	-	222 39
23, ...	1	50 00	60	3 00	-	15 00	4 00	-	3 60	24 23	3 10	3 40	106 93
Total, . .	10	$281 43	$18 60	$18 00	$30 00	$67 50	$16 70	$10 00	$72 60	$196 99	$20 61	$5 40	$737 83

TABLE XI. — *A Detailed Comparative Study of Distribution Costs of Four Producing Distributors and Five Dealers* — Con.

(A) PRODUCERS — *Concluded.*

Maintenance.

PRODUCER'S NUMBER.	Repairs.	Sundries.	Shoeing.	Feed.	Bottles.	Cans.	Total.
9,	$95 00	$31 50	$72 00	$540 00	$48 00	$2 23	$788 73
12,	125 00	29 45	54 00	540 00	50 00	12 50	810 95
18,	80 00	22 75	72 00	352 56	234 00	-	761 31
23,	50 00	19 81	24 00	156 00	35 00	-	284 81
Total,	$350 00	$103 51	$222 00	$1,588 56	$367 00	$14 73	$2,645 80

Circulating Capital.

PRODUCER'S NUMBER.	Rent.	Soap.	Caps.	Ice.	Light.	Fuel.	Stationery.	Insurance and Taxes.	Interest.	Surplus and Shrinkage.	Bad Bills.	Sundries.	Total.
9,	$144 00	$10 20	$13 50	$140 00	$6 60	$48 00	$6 00	$0 50	$76 40	-	$30 00	$27 00	$502 20
12,	-	15 00	15 00	50 00	23 00	50 00	20 00	98 50	182 75	-	25 00	54 00	533 25
18,	78 00	10 00	27 38	80 00	6 75	50 00	10 00	10 50	-	-	50 00	30 00	352 63
23,	24 00	6 00	16 00	70 00	12 00	-	10 00	4 50	28 32	-	10 00	25 00	205 82
Total,	$246 00	$41 20	$71 88	$340 00	$48 35	$148 00	$46 00	$114 00	$287 47	-	$115 00	$136 00	$1,593 90

Labor.

Producer's Number.	Total.	Producer's Number.	Total.
9,	$1,790 20	23,	$842 90
12,	2,536 85	Total,	$6,748 58
18,	1,578 63		

Grand Total.

Producers: —		
Depreciation,	$737 83	
Maintenance,	2,645 80	
Circulating capital,	1,593 90	
Labor,	6,748 58	
		$11,726 11

TABLE XI. — *A Detailed Comparative Study of Distribution Costs of Four Producing Distributors and Five Dealers* — Con.

(B) DEALERS.

Investment.

DEALER'S NUMBER.	HORSES.		Milk Shed.	Ice House.	Stable.	Boiler.	Washer.	Filler.	Pasteurizer.	Ice Chest.	Harness.	Wagons.	Boxes.	Cans.	Office.	Total.
	Number.	Value.														
13,	4	$1,100 00	-	-	-	$150 00	$15 00	$45 00	$40 00	$70 00	$140 00	$815 00	$50 00	-	-	$2,425 00
14,	3	900 00	$700 00	$300 00	$2,000 00	225 00	85 00	200 00	-	-	150 00	855 00	118 75	$85 00	$50 00	5,668 75
24,	12	3,300 00	5,000 00	2,000 00	2,000 00	400 00	1,000 00	200 00	-	-	800 00	4,115 00	525 00	400 00	-	19,740 00
26,	4	900 00	-	50 00	-	178 27	35 00	161 00	800 00	-	250 00	860 00	80 00	80 00	-	3,394 27
28,	5	1,375 00	-	-	-	450 00	-	50 00	-	100 00	235 00	1,135 00	68 75	48 00	-	3,461 75
Total,	28	$7,575 00	$5,700 00	$2,350 00	$4,000 00	$1,403 27	$1,135 00	$656 00	$840 00	$170 00	$1,575 00	$7,780 00	$842 50	$613 00	$50 00	$31,689 77
Depreciation.																
13,	4	$115 68	-	-	-	$15 00	$6 00	-	$4 00	$7 00	$28 00	$77 34	$10 00	-	-	$263 02
14,	3	66 67	$21 00	$9 00	$60 00	22 50	8 50	$20 00	-	-	30 00	124 50	14 85	-	$5 00	382 02
24,	12	360 00	150 00	200 00	60 00	26 67	100 00	20 00	-	-	160 00	602 17	131 25	-	-	1,810 09
26,	4	76 92	-	1 50	-	17 82	2 33	10 73	53 33	-	42 50	54 66	16 00	$20 00	-	295 79
28,	5	125 00	-	-	-	45 00	-	10 00	-	10 00	58 75	140 63	13 75	-	-	403 13
Total,	28	$744 27	$171 00	$210 50	$120 00	$126 99	$116 83	$60 73	$57 33	$17 00	$319 25	$999 30	$185 85	$20 00	$5 00	$3,154 05

Maintenance.

Dealer's Number.	Repairs.	Sundries.	Shoeing.	Feed.	Bottles.	Cans.	Total.
13,	$90 00	$79 10	$72 00	$547 50	$75 00	-	$863 60
14,	178 00	68 63	72 00	1,095 00	156 25	$8 50	1,578 38
24,	764 00	158 75	360 00	810 94	700 00	160 00	2,953 69
26,	225 56	50 56	48 00	313 42	100 00	-	737 54
28,	256 00	95 50	120 00	1,200 00	300 00	10 67	1,982 17
Total,	$1,513 56	$452 54	$672 00	$3,966 86	$1,331 25	$179 17	$8,115 38

Circulating Capital.

Dealer's Number.	Rent.	Soap.	Caps.	Ice.	Light.	Fuel.	Stationery.	Insurance and Taxes.	Interest.	Surplus and Shrinkage.	Bad Bills.	Sundries.	Total.
13,	$180 00	$13 50	$32 85	$196 00	$21 00	$50 00	$50 00	$5 50	$121 25	$2 25	$100 00	$37 00	$809 35
14,	-	32 00	80 00	200 00	33 15	56 25	75 00	154 50	283 44	-	25 00	33 36	972 70
24,	-	216 00	136 88	100 00	172 00	365 00	400 00	605 11	987 00	-	1,478 02	135 00	4,595 01
26,	246 00	40 00	45 00	212 50	20 40	66 00	45 45	88 50	169 71	36 50	50 00	33 60	1,053 66
28,	180 00	18 00	51 00	375 00	33 00	100 00	30 00	45 50	173 08	200 00	150 00	44 20	1,399 78
Total,	$606 00	$319 50	$345 73	$1,083 50	$279 55	$637 25	$600 45	$899 11	$1,731 48	$238 75	$1,803 02	$283 16	$8,830 50

TABLE XI. — *A Detailed Comparative Study of Distribution Costs of Four Producing Distributors and Five Dealers* — Con.

(B) DEALERS — *Concluded.*

Labor.

DEALER'S NUMBER.	Total.	DEALER'S NUMBER.	Total.
13,	$2,706 00	26,	$2,745 70
14,	3,822 50	28,	4,467 76
24,	9,606 91	Total,	$23,318 87

Grand Total.

Dealers: —		
Depreciation,	$3,154 05	
Maintenance,	8,115 38	
Circulating capital,	8,830 50	
Labor,	23,348 87	
		$43,448 80

(C) SUMMARIES.

Producers.

PRODUCER'S NUMBER.	Depreciation.	Maintenance.	Circulating Capital.	Labor.	Total Cost.	Wagons.	QUARTS MILK DISTRIBUTED.			Quarts Cream Yearly.
							RETAIL MILK.		Wholesale.	
							Daily.	Yearly.		
9,	$156 38	$788 73	$502 20	$1,790 20	$3,237 51	2	440	160,600	29,200	-
12,	252 13	810 95	533 25	2,536 85	4,132 68	2	450	164,250	87,600	-
18,	222 39	761 31	352 63	1,578 63	2,914 96	1	400	146,000	-	-
23,	106 93	284 81	205 82	842 90	1,440 46	1	230	83,950	6,205	-
Total or average,	$737 83	$2,645 80	$1,593 90	$6,748 58	$11,725 61	6	1,520	554,800	123,005	-

PRODUCER'S NUMBER.	YEARLY COST.		QUARTS DISTRIBUTED PER —			MILES TRAVELED PER —		Cost per Mile.	CUSTOMERS SERVED.	
	Retail.	Per Quart.	Horse.	Mile.	Customer.	Day.	Customer.		Wholesale.	Retail.
9,	$3,091 57	$0 0192	146.66	29.3	1.189	15	.040	$0 56	4	370
12,	3,694 68	0251	150.00	18.8	1.000	24	.053	42	15	450
18,	2,914 96	0199	133 33	18 1	1.230	22	.067	36	-	325
23,	1,404 44	0167	230.00	15 3	1.150	15	.074	26	1	200
Total or average,	$11,105 65	$0 0200	152.00	20.0	1.130	76	.056	$0 40	20	1,345

TABLE XI. — *A Detailed Comparative Study of Distribution Costs of Four Producing Distributors and Five Dealers* — Con.

C. SUMMARIES — *Concluded.*

Dealers.

DEALER'S NUMBER.	Depreciation.	Maintenance.	Circulating Capital.	Labor.	Total Cost.	Wagons.	QUARTS MILK DISTRIBUTED.			Quarts Cream Yearly.
							RETAIL MILK.		Wholesale.	
							Daily.	Yearly.		
13,	$263 02	$803 60	$809 35	$2,706 00	$4,641 97	3	425	155,125	-	2,190
14,	382 02	1,578 38	972 70	3,822 50	6,755 60	3	1,100	401,500	182,500	-
24,	1,810 09	2,953 69	4,595 01	9,606 91	18,965 70	7	2,080	759,200	379,600	-
26,	295 79	737 54	1,053 66	2,745 70	4,832 69	3	650	237,250	102,200	-
28,	403 13	1,982 17	1,399 78	4,467 76	8,252 84	3	800	292,000	43,800	2,920
Total or average,	$3,154 05	$8,115 38	$8,830 50	$23,348 87	$43,448 80	19	5,055	1,845,075	708,100	5,110

DEALER'S NUMBER.	YEARLY COST.		QUARTS DISTRIBUTED PER —			MILES TRAVELED PER —		Cost per Mile.	CUSTOMERS SERVED.	
	Retail.	Per Quart.	Horse.	Mile.	Customer.	Day.	Customer.		Wholesale.	Retail.
13,	$4,574 27	$0 0295	106.25	23.6	1.416	18	.060	$0 70	-	300
14,	5,843 10	0145	366.66	45.8	1.100	24	.024	66	25	1,000
24,	17,067 70	0225	173.33	59.4	1.094	35	.018	1 50	60	1,900
26,	4,324 69	0182	162.50	50.0	1.083	13	.021	91	10	600
28,	7,931 64	0272	160.00	26.6	1.230	30	.046	76	8	650
Total or average,	$39,741 40	$0 0216	180.50	42.1	1.111	120	.027	$0 91	103	4,450

The Producer as a Distributor in Comparison with the Dealer.

Any comparison of costs that fails to recognize the difference between the business of the producer who distributes his own milk, or his own milk plus some purchased from his neighbors, and the dealer who buys all the milk he distributes, is surely inadequate. The data in Tables XI and XII are inserted to exhibit this comparison in some detail. The records of four producers and five distributors whose cost accounts were kept with unusual care are chosen for this comparison. As usual the figures on cost per quart (Table XI) are based on milk sold at retail. From the total cost of doing business 3 cents per quart were deducted for retail cream sold and one-half cent per quart for milk delivered at wholesale.

The most striking reflection in the whole comparison is the great difference in costs as between individuals whether producers or dealers. Producers' retailing costs run from 2.51 to 1.67 cents per quart, and dealers' from 2.95 cents to less than half that much, or 1.45 cents per quart. Such wide variations between individuals indicate the fruitlessness of drawing any but the most general conclusions from the final averages. It is evident that much remains to be done in the study of economical and efficient methods of distribution and in profitable investment in equipment and buildings.

1. According to these figures, the average producer is able to distribute retail milk more cheaply, it costing him 2 cents per quart against 2.16 cents for the dealer. An analysis of the figures, however, shows that the dealer's investment is about 12 per cent. greater than the producer's per 1,000 quarts of milk handled. There is some difference in maintenance, but on the whole this is in favor of the dealer.

2. The labor bill of the average dealer is noticeably greater per quart, notwithstanding he is near his market and saves in time. This is indicated by the fact that the dealer retails 42 quarts per mile to the producer's 20 — more than double. The dealer almost always has the advantage of shorter delivery routes. The producer must often travel several miles from his farm before he reaches his first customer and retrace this distance after his load has been delivered. In this instance the producer averaged 12⅔ miles per wagon; the dealer, only 6 miles per wagon.

3. The producer has the advantage in depreciation and working capital. In other words, the dealer invests more in his equipment and buildings, naturally increasing the depreciation and circulating capital accounts. The items of shrinkage and bad bills are significant. These two items are the most important of the overhead costs of the dealers here noted. As a whole the overhead charges and current supplies, *i.e.*, the circulating capital, of the dealers per 1,000 quarts handled are more than 60 per cent. higher than those of the producers.

4. The dealer gives better service in pasteurizing and clarifying and his labor account is also somewhat reduced by use of better labor-saving devices for washing, filling, etc.

TABLE XII. — *Analysis of Costs of Three Individual Dealers and Two Producing Distributors, giving Total Costs and Cost per Thousand Quarts of All Milk and Cream sold daily.*

	Quarts sold daily.	COST PER QUART.		INVESTMENT.		DEPRECIATION.		CIRCULATING CAPITAL.		MAINTENANCE.		LABOR.		EXPENSE.	
		All Sales (Cents).	Retail Milk[1] (Cents).	Total.	Per 1,000 Quarts.	Total.	Per 1,000 Quarts.	Total.	Per 1,000 Quarts.	Total.	Per 1,000 Quarts.	Total.	Per 1,000 Quarts.	Total.	Per 1,000 Quarts.
Dealer: —															
No. 13,	430	2.95	2.95	$2,425	$5,640	$263	$612	$809	$1,876	$864	$2,009	$2,706	$6,293	$4,642	$10,790
No. 14,	1,600	1.15	1.45	5,669	3,543	382	239	973	608	1,578	986	3,823	2,389	6,756	4,222
No. 24,	3,120	1.66	2.24	19,740	6,327	1,810	580	4,595	1,472	2,954	947	9,607	3.079	18,966	6,078
Producer: —															
No. 12,	690	1.64	2.51	3,615	5,239	252	365	533	772	811	1,175	2,537	3,677	4,133	5,989
No. 23,	247	1.60	1.67	837	3,337	107	433	206	834	285	1,154	843	3,412	1,441	5,833

[1] Retail costs in this column obtained by deducting .5 cent per quart for wholesale milk delivery and 3 cents per quart for cream. All remaining costs are charged to retailing.

One must bear in mind, however, that the expenses of collecting the milk are not charged to the dealer. The above figures are calculated from the time the milk arrives at the dairy or distributing plant until it reaches the consumer, the cost of transportation from the producer to the dealer's plant, including freight and haulage from producer to shipping point and from shipping destination to milk plant, not being included, whereas the producer's costs include haulage to the city. To this degree the figures are not comparable. The dealer sometimes collects from the producer, sometimes pays a higher price for milk delivered at his plant, sometimes pays freight charges. Usually the difference between milk collected by the dealer and milk delivered to the dealer is about one-half cent per quart.

When milk is shipped from a distance it is usually laid down at the dealer's plant for a price equal to or less than the local producing distributor can produce it. In such case the dealer and the producer who sells his own milk may both start from their doors with loads of milk equal in value. When the dealer procures local milk he usually pays one-half cent per quart more for it if brought to his dairy.

Further analysis, both from a collective and an individual standpoint, indicates that the variation in the cost of distribution is related closely to the number of quarts delivered per horse in conjunction with the quarts delivered per mile. One dealer (No. 14) with three horses delivers 1,600 quarts daily (including 500 quarts of wholesale milk in cans). Although his mileage per horse (8 miles) is higher than most of the dealers, his exceptionally heavy delivery, 45.8 quarts per mile, helps to bring his retail cost down to 1.45 cents per quart. Of the producers, No. 23 delivers at less cost than others in the group, although his mileage is 15 per horse; this is accounted for by the large load hauled — 230 retail quarts per horse — and his comparatively small overhead charges. Producer No. 9 carries 520 quarts on two wagons. His horse load is good and his delivery per mile (29.3 quarts), retail and wholesale, is larger than any other producer in the group — in fact, nearly 50 per cent. above the average.

Table XII will repay careful study. The analysis of cost per 1,000 quarts of milk delivered daily is excellent for comparative study and reveals very striking individual variations. No. 13, who uses four horses and travels 18 miles, with an average load of 107 quarts per horse to deliver 430 quarts daily, has high cost items in all respects. His labor and working capital accounts are nearly thrice those of No. 14 and his other items twice as great. Dealer No. 24 makes up for his high investment and large depreciation and overhead costs by a low maintenance expense and a small labor bill. His labor charge is only one-half that of No. 13, and $700 less per 1,000 quarts than that of the average producer.

The efficiency of No. 14 has been noted above. His economies extend to every division of his business. His labor bill is extremely small and except for horse feed his maintenance costs are very low.

TABLE XIII. — *Cost of Distribution of Special Milk.*

Summary Statement (Two Plants).

DEALER.	Investment.	Depreciation.	Maintenance.	Circulating Capital.	LABOR.		Total Cost.	RETAIL DISTRIBUTION.	
					Preparation.	Delivery.		Daily.	Yearly.
No. 1,	$5,985[1]	$759 50	$1,833 29	$1,798 28	$383 25	$1,035 69	$5,810 01	350	127,750
No. 2,	–[2]	85 00	282 18	604 16	138 00	876 00	1,985 34	102	37,200

DEALER.	Cost per Quart (Cents).	Miles Daily.	Cost per Mile (Cents).	Quarts per Mile.	Quarts per Customer.	Miles per Customer.	Customers per Mile.	Total Customers.	Selling Price (Cents).
No. 1,	4.54	47[3]	23.76[4]	7.45	1.27	.171	5.8	275	12
No. 2,	5.34	15	36.00	6.80	.70	.103	9.7	145	12

Cost per 1,000 Quarts Distributed Yearly.

DEALER.	Depreciation per 1,000 Quarts.	Maintenance per 1,000 Quarts.	Circulating Capital per 1,000 Quarts.	Labor per 1,000 Quarts.	Total per 1,000 Quarts.
No. 1,	$5 94	$14 35	$14 08	$11 11	$45 48
No. 2,	2 63	8 74	18 72	31 42	61 51

[1] Including $2,770 for Ford car and White motor truck.

[2] Rents buildings, uses horses, wagons, etc., for other purposes.

[3] Including collection, 67.

[4] Including collection.

Cost of Delivery of Special Milk.

Fortunately reliable data were secured from four distributors who had kept accurate accounts for a number of years. Two of these produced and distributed what they termed "special" milk — unpasteurized, but held to be equal in purity and cleanliness to certified milk. The term "special" is very unsatisfactory. There is no standard for such milk. Whether the term means anything depends on the producer and seller. Frequently the milk is of excellent quality. In these instances it is sold to the consumer at 12 cents per quart. This "special" milk entails extra care, extra labor and good equipment and requires a special market; moreover, the distributors must of necessity travel far to dispose of their product. Distributor No. 1 traversed 47 miles daily to dispose of 350 quarts — but 7.45 quarts per mile traveled. In case No. 2, 15 miles were traveled daily to dispose of 83 quarts of "special" milk, 19 quarts of skimmed milk, and 4.9 quarts of cream; disregarding the skimmed milk, this is equal to 5.86 quarts of "special" milk and cream per mile traveled.

No. 1 has much higher depreciation and maintenance expense than No. 2, due to the use of a Ford car and White motor truck. The extra cost, however, is offset by the reduced cost of labor, which is but a trifle more than a third that of No. 2 ($11.11 as against $31.42 per 1,000 quarts). At least twelve hours of labor were saved daily at 15 cents per hour. As in the case of distributors of market milk, the same conclusion can be drawn from the above figures, namely, economic distribution depends on the number of quarts per horse, in conjunction with the quarts per mile.

Cost of Collection and Distribution of Wholesale Milk in Cans.

These figures demonstrate the reasonableness of calculating one-half cent per quart for the cost of delivering wholesale milk, as we have done in the case of mixed delivery in the figures given in the previous pages. In this plant the cost was a little more than three-fourths of a cent per quart including collection from producers. Two hours daily were occupied by a man and two horses for collecting and six hours for delivery. It is contended, however, that the motor truck is more economical for wholesale delivery, provided the truck can be kept fully occupied and the location will permit its use during the winter.

TABLE XIV.

	Investment.	Depreciation.	Maintenance.
Buildings,	$1,280	$38 40	$70 50
Equipment,	597	62 50	–
Horses,	600	65 00	258 37
Totals,	$2,477	$165 90	$328 87

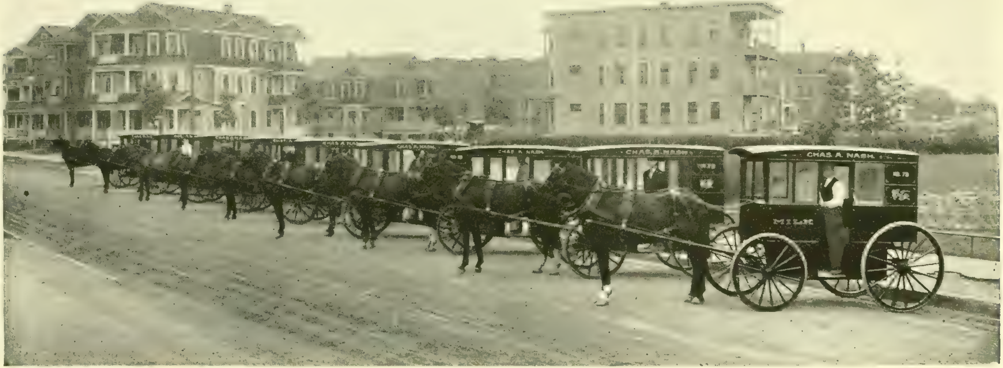
Circulating capital: —	
Ice,	$100 00
Interest,	123 85
Shrinkage,	86 68
Other,	91 20
Total,	$401 73
Labor,	$803 00
Total costs,	$1,699.50
Milk handled: —	
Daily (quarts),	6000
Yearly (quarts),	219,000
Cost per quart (cents),	.78
Cost per mile (cents),	24.00
Mileage —	
Collection,	4
Delivery,	15
Customers,	12
Quarts per customer,	50
Miles per customer,	1.58
Quarts per mile,	31.60
Quarts per horse,	300

Motor Truck Delivery.

The actual cost figures of motor truck milk delivery are of interest in view of the increasing prevalence of these vehicles. Notice that the per mile cost for horse delivery as given above is 24 cents based on about 7,000 miles traveled yearly. The costs below are based on 10,000 miles annually. Under ordinary conditions the truck equipment would deliver the milk on the above route in four hours, one-half the time taken by horses.

The operating cost of a motor truck suitable for distribution of wholesale milk or of "special milk," where the haul is long or loads are heavy, is given below. These figures apply to a White motor truck, three-quarters to 1 ton, in actual operation (1915) by a producing distributor of milk.

	Per Mile.
Gasoline,	$0.0100
Oil,	.0016
Grease, waste, etc.,	.0010
Running expenses,	.0050
Tires, total cost per set, $175; guaranteed mileage, 5,000,	.0350
Overhauling and painting after 20,000 miles, approximately $350,	.0175
Interest 5 per cent, depreciation 20 per cent, on an investment of $2,250 =$562.50 on approximate yearly mileage of 10,000,	.0562
Insurance (fire $1\frac{7}{8}$ per cent., collision $2\frac{3}{5}$ per cent.) on $2,250 = $96.18 on mileage of 10,000,	.0096
Driver, $850 per year, over mileage of 10,000,	.0850
Total cost per mile,	$0.2209


CHAS. A. NASH.
MILK

The retail delivery equipment of one dealer.

COST OF DISTRIBUTION OF CREAM.

The distribution of cream exclusively is analogous to the distribution of "special" or of certified milk, excepting that the cost of delivery is increased because the overhead charges are high in comparison with the quantity delivered. Cream from dealers who delivered a small quantity of cream to their regular milk customers is not subject to this high overhead charge and need not be considered here. Only one plant delivering cream exclusively is included in this study. A summarized statement of its expenses is presented below. These figures take no account of bottles which were paid for by the customers. Notwithstanding this fact, the long route and small daily delivery raises the cost to more than 7.5 cents ($0.0759) per quart, as against 4.5 and 6.1 cents for retailing "special" milk.

Summary of Costs of delivering Cream (One Plant).

Depreciation,	$112 23
Maintenance,	543 25
Circulating capital,	399 10
Labor,	1,155 90
Total yearly cost,	$2,210 48
Cost per 1,000 quarts yearly,	$75 91
Cream delivered yearly (quarts),	29,120
Cream delivered daily (six days a week) (quarts),	93.3
Customers,	95
Quarts per customer,	.98
Cost per quart to deliver,	$0.0759
Miles traveled,	18
Cost per mile,	$0.33
Quarts per mile,	5.18
Miles per customer,	.19
Customers per mile,	5.3

SIGNIFICANT FACTS OF DISTRIBUTION SHOWING INDIVIDUAL VARIATIONS.

Table XV is an attempt to exhibit the salient facts of milk delivery by individual milkmen. Amherst and Walpole distributors are not included; wholesale dealers and those using motor trucks, cream and skimmed-milk handlers and those who furnished imperfect data are also omitted.

TABLE XV. — *Grouping of Sixty-six Individual Distributors on Basis of Cost per Quart of retailing Milk showing Number of Quarts retailed, Quarts and Miles per Wagon Daily, Quarts retailed per Mile and Customers per Mile together with Total Daily Distribution, Wholesale and Retail.*

Group I.

NUMBER IN GROUP.	RETAIL COST, CENTS PER QUART.		Number of Routes.	QUARTS SOLD DAILY AT RETAIL.		Miles traveled per Wagon daily.	Quarts retailed per Mile per Wagon.	Customers per Mile.	Quarts per Day, Wholesale and Retail.
	Group.	Individual.		Total.	Per Wagon.				
4,	Under **1**.5	1.05	2	460	230	10.0	23.0	19.5	700
		1.21	1	545	545	8.0	68.0	68.7	620
		1.21	2	500	250	10.0	25.0	10.0	715
		1.45	3	1,100	367	8.0	45.8	41.7	1,600
Average,	-	-	-	651	326	9.0	38.7	29.7	908.7
Group II.									
14,	**1.5** to **2**	1.61	5	1,200	240	8.0	30 0	29.4	1,550
		1.63	1	450	450	12.0	37.5	58 3	550
		1.64	2	560	280	4.0	70.0	47.5	720
		1.67	1	230	230	15.0	15.3	13 3	247
		1.67	2	650	325	14.0	23.2	17.9	750
		1.82	3	650	217	4.3	50.0	46.1	930
		1.85	2	622	311	7.5	41.5	33 3	662
		1.86	2	550	275	7.0	39.3	33.8	750
		1.89	1	280	280	5.0	56.0	34.0	312
		1.92	2	440	220	7.5	29.3	24.6	520
		1.93	1	200	200	7.0	28.6	22.8	215
		1.94	2	400	200	12.0	16.7	16.7	500
		1.96	1	428	428	20.0	21.4	19 0	445
		1.99	2	400	200	11.0	18.1	14 8	400
Average,	-	-	-	504	261	8.8	29.6	26 6	610.8

Group III.

16,	**2 to 2.5**	2.02	2	530	265	6.5	40.7	31.6	660
		2.04	2	500	250	15.0	16.6	16.7	668
		2.11	1	420	420	6.0	70.0	58.3	490
		2.12	1	308	308	12.0	25.7	21.7	340
		2.12	2	650	325	20.0	16.2	8.8	1,017
		2.18	1	214	214	10.0	21.4	18.5	214
		2.22	1	330	330	8.0	41.2	28.1	378
		2.25	4	850	213	5.5	38.6	31.4	1,050
		2.25	7	2,080	297	5.0	59.4	54.3	3,120
		2.32	3	700	233	9.0	25.9	20.6	1,400
		2.32	2	360	180	8.0	22.5	28.1	640
		2.37	2	552	276	5.0	55.2	45.0	992
		2.42	2	280	140	7.5	18.7	20.0	460
		2.45	2	300	150	5.0	30.0	20.0	502
		2.47	1	300	300	15.0	20.0	16.7	306
		2.47	1	225	225	22.0	10.2	9.0	239
Average,	–	–	–	537	253	8.6	29.5	25.1	780

Group IV.

13,	**2.5 to 3**	2.51	4	1,100	275	8.0	31.4	31.3	1,217
		2.51	2	450	225	12.0	18.8	18.8	690
		2.54	2	300	150	8.0	18.8	20.0	300
		2.57	2	464	232	15.0	15.5	12.7	500
		2.72	3	800	267	10.0	26.6	21.7	928
		2.78	1	175	175	12.0	14.5	12.5	257
		2.78	7	2,000	286	10.0	28.6	20.0	2,320
		2.79	2	320	160	5.0	32.0	20.0	320
		2.81	2	380	190	10.0	19.0	12.5	525
		2.86	5	1,400	280	10.0	28.0	24.2	1,654
		2.87	1	320	320	5.0	64.0	50.0	480
		2.95	2	425	213	9.0	23.6	16.7	431
		2.97	2	300	150	8.0	18.8	12.5	447
Average,	–	–	–	649	241	9.5	25.0	20.3	774.5

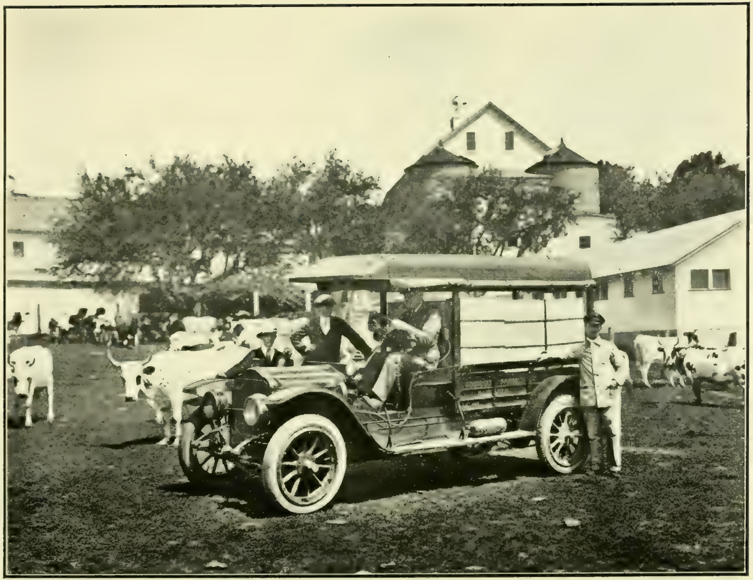
TABLE XV — *Grouping of Sixty-six Individual Distributors on Basis of Cost per Quart of retailing Milk showing Number of Quarts retailed, Quarts and Miles per Wagon Daily, Quarts retailed per Mile and Customers per Mile together with Total Daily Distribution, Wholesale and Retail* — Con.

Group V.

NUMBER IN GROUP.	RETAIL COST, CENTS PER QUART.		Number of Routes.	QUARTS SOLD DAILY AT RETAIL.		Miles traveled per Wagon daily.	Quarts retailed per Mile per Wagon.	Customers per Mile.	Quarts per Day, Wholesale and Retail.
	Group.	Individual.		Total.	Per Wagon.				
12,	3 to 3.5	3.01	2	300	150	10.0	15.0	12.0	675
		3.02	1	216	216	4.0	54.0	37.5	376
		3.06	2	450	225	4.0	56.3	62.5	834
		3.11	1	240	240	5.0	48.0	38.0	360
		3.12	1	268	268	10.0	26.8	16.2	324
		3.19	1	260	260	10.0	26.0	26.0	300
		3.21	4	1,080	270	6.5	41.5	30.8	1,315
		3.23	3	650	217	4.0	54.2	50.0	810
		3.26	2	440	220	15.0	14.6	10.6	451
		3.35	1	97	97	12.0	8.0	2.8	218
		3.38	11	3,146	286	8.0	35.7	39.8	3,392
		3.50	2	290	145	7.5	19.3	16.7	353
Average,	-	-	-	620	240	7.7	30.9	29.2	784

Group VI.

NUMBER IN GROUP.	RETAIL COST, CENTS PER QUART.		Number of Routes.	QUARTS SOLD DAILY AT RETAIL.		Miles traveled per Wagon daily.	Quarts retailed per Mile per Wagon.	Customers per Mile.	Quarts per Day, Wholesale and Retail.
	Group.	Individual.		Total.	Per Wagon.				
7,	Over 3.5	3.66	3	1,065	355	6.0	59.1	38.9	1,065
		3.68	1	150	150	15.0	10.0	8.0	152
		3.82	1	370	370	12.0	30.8	16.7	374
		4.47	1	186	186	6 0	31.0	41.6	306
		4.70	2	175	88	4.0	22.0	18.7	289
		5.34	1	102	102	15.0	6.8	9.7	107
		5.57	1	175	175	15.0	11.6	9.3	295
Average,	-	-	-	318	222	9.0	25.0	19.0	370



Motor truck equipment of a successful producing distributor.

The per quart costs of retail delivery of the 66 distributors considered are approximately as follows: —

4, or 6 per cent., less than 1.5 cents.
14, or 21 per cent., between 1.5 and 2 cents.
16, or 24 per cent., between 2 and 2.5 cents.
13, or 20 per cent., between 2.5 and 3 cents.
12, or 18 per cent., between 3 and 3.5 cents.
7, or 11 per cent., over 3.5 cents.

The first striking observation is the wide variation in costs, and the comparatively uniform distribution between 1.5 and 3.5 cents.

The second is the fact that there is no marked correlation between costs and size of business; dealers distributing 300 quarts or less and dealers distributing more than 1,000 quarts daily are found in every group except the first. The third group contains as many dealers handling less than 500 quarts daily as any group and more dealers handling more than 1,000 quarts daily than any other group.

Third, considered by groups, the cost per quart of retailing increases and the size of the retail load decreases from the first to the sixth group. It should be noted that the high average retail load of the first group is due to one dealer whose load was exceptionally heavy.

Fourth, some correlation is discernible between the number of quarts retailed per mile of haul and the cost per quart, the more quarts per mile the less the cost; but the correlation is not consistent. The average delivery for Group III is 29.5 quarts per mile; that of Group V is 30.9 quarts per mile, though the average cost per quart of delivery of the latter is about 50 per cent. higher than the former. These two factors, however — the size of the load and the density of delivery (quarts per mile) — are two very important considerations in milk delivery.

Fifth, the individual variations in the number of quarts retailed per mile per wagon, within the groups, are very significant. In Group I, for example, one dealer distributes 23 and another 68 quarts per mile. In Group II the variations run from 15 to 70; in Group III, from 10 to 70, and in Group V, from 8 to 56 quarts per mile. Under these conditions it is very evident that the costs of milk delivery must vary tremendously.

Finally, the cost of delivery is closely related to the miles traveled per customer (or, inversely, the number of customers per mile), running from one-thirtieth of a mile between deliveries in the first group to one-nineteenth of a mile in the sixth group. Nothing more strikingly indicates the individual differences in delivery conditions than the customers served per mile traveled. The first group contains one dealer with a record of 68 customers and another with only 10 customers a mile. The third group shows variations between 9 and nearly 60 customers. Group V has one dealer who serves 62 customers a mile, and another who serves less than 3. The significance of these relationships will be considered under "Disadvantages of Competitive Distribution."

Some Obvious Disadvantages in Competitive Distribution of Milk.

The investigation clearly indicates the very wide diversity of costs in the retailing of milk. At the same time the milk-retailing service under competitive conditions is fairly satisfactory. The consumer usually gets his milk on time and in such quantities as he requires. If the quality of milk delivered by one dealer is not satisfactory, several others are available. It is questionable, however, whether the consumer does not pay roundly for this competitive service. Several economic disadvantages may be indicated.

1. *Overcapitalization.* — The great majority of the plants visited are of one or two wagon capacity. Eighty-four per cent. of them deliver 1,000 quarts or less daily; 59 per cent., 500 quarts or less; and 23 per cent., 300 or less. To meet the demands of his customers, comply with the milk regulations and compete with other milkmen the progressive dealer installs machinery for washing, filling and capping bottles, clarifying, pasteurizing and cooling his milk.

One recognizes that milk is highly perishable and that the time for the processing is necessarily short. Some dealers, however, have installed pasteurizers capable of disposing of 400 gallons per hour, although their total quantity handled is but 900 quarts per day. Some have bottle-fillers filling 12 bottles at once when handling only 350 bottles daily. This means running the plant below its capacity. A few dealers have buildings or horses and wagons much more ample and expensive than necessary. In some instances the total investment runs to 1.5 cents ($0.015) a quart sold yearly, whereas the average investment for that size of business is less than one-half cent ($0.0043) a quart; in other instances the investment is 3.4 cents a quart when the average is less than 1 cent ($0.0095) per quart for plants of similar capacity.

2. *Small Daily Deliveries per Horse.* — A load for a good horse over a good road is 300 quarts of milk in bottles but the investigation disclosed the fact that the usual load is much less. The average load of 10 distributors in Springfield is 216 quarts per horse (307 per wagon), and of 28 Worcester milkmen, 234.4 quarts per horse (346.1 per wagon), including wholesale milk in cans. On the other hand, a rather large percentage of dealers haul 300 quarts or more per wagon. More than 12 per cent. of the milkmen retail 15 quarts or less per mile of travel in contrast to nearly 14 per cent. who average more than 55 quarts a mile. The average delivery is about 32 quarts per mile per wagon. That the size of load bears a direct relation to the cost of delivery is shown in Table XV.

3. *Long Hauls are usually Uneconomical.* — Several instances can be cited of distributors who traveled from 10 to 15 miles to retail from 100 to 200 quarts of milk. When the distributor is a long distance from his market or when the distance between stops is great, there is a considerable waste both in man and horse labor through lost time. This is somewhat offset by the drivers making their daily entries during these intervals.

More than 20 per cent. of the routes average 14 miles long and almost half of them average 13 miles.

4. *Loss of Bottles.* — In Worcester 30 dealers, delivering 15,809 quarts per day, claim a loss of $4,913.42 yearly in bottles. Most of the loss in bottles is the fault of consumers. Bottles are frequently unfit for service when returned and many dealers state that they destroy such bottles. Milk bottles are handy receptacles during preserving season, and one dealer told of a housewife who proudly exhibited 100 quart bottles filled with preserves and, to add insult to injury, asked him for a sufficient number of caps to cover them.

5. *Bad Debts.* — This waste is common to all businesses which extend credit but the competitive milk dealer suffers more than ordinary loss because unscrupulous persons have a variety of methods for evading the payment of small bills. To prevent this loss many dealers make special trips for collecting. Bad debts cost Springfield and Worcester about 2½ per cent. of all costs of distribution. These losses aggregate $0.54 per 1,000 quarts in Springfield and $0.82 per 1,000 quarts in Worcester. The loss depends entirely on the class of trade, however, and no comparisons or general conclusions should be drawn from these figures.

6. *Shrinkage.* — This loss, seemingly insignificant, amounts to a considerable sum in the course of a year. It cannot, however, be wholly charged to distribution, as a certain amount is lost in transportation through carelessness in transit and leaky and dented cans. A good filling apparatus reduces this loss to a minimum in the dairy and whatever loss may be sustained in transit is probably borne by the producer who ships in cans. In general the shipper receives payment for only 8 quarts per can, though the can usually contains 8¼ to 8½ quarts.

7. *Surplus and Spoilage.* — This item is considerable in all towns and cities visited and it is one of the great and ever-present problems which the dealer is trying to overcome. Three factors contribute to the problem of surplus milk: —

(*a*) Restaurants and lunch counters which close on Sunday.
(*b*) Decreased demand owing to depopulation of cities during summer.
(*c*) Excessive production of milk at certain seasons.

The solution of the first factor is the business of the dealer. But to solve the question of decreased consumption, which occurs regularly and covers a long period, and of overproduction during certain months of the year is really the business of the producer.

Closely allied to shrinkage and surplus is spoilage. Milk which cannot be delivered at once is very likely to sour and so become a total loss. Naturally this waste is more prevalent during the summer at the time of surplus production. The producer who delivers his own milk can sometimes regulate the supply by producing more winter milk, by feeding some milk to calves or pigs, or he may be able to sell it to a creamery. The small dealer can do little but dump the surplus into the sewer.

In the aggregate the question of surplus milk is a big one which many dealers, large and small, have wrestled with for years with little success. An emergency butter and cheese factory managed co-operatively, which will utilize part of the existing equipment and take care of all the extra milk, is, perhaps, the best suggestion. Some relief will come from a form of contract with the producers which provides for definite variations in supply. At best there will always be a loss at this point.

The loss sustained by 10 dealers in Springfield, delivering 9,600 quarts wholesale and retail daily, amounted to $1,661.50 per year, or 52 cents per 1,000 quarts retailed annually. This does not represent the whole value of the milk; it was disposed of at the above loss.

8. *Duplication in Routes.* — The economic waste through duplication of milk routes was evident in all the towns and cities visited. From personal observation, at an apartment house containing four families, three milkmen called to deliver 4 quarts of milk; at another fourth-floor tenement three different milkmen climb four flights every day to deliver 6 pints to four families. Between the hours of 3 A.M. and 7 A.M. 42 milk wagons were observed to pass down Bowdoin Street, Worcester; only one failed to deposit milk within a distance of 400 yards from the observer. Similar conditions were found in all the other towns and cities visited.

In Worcester 103 one-horse milk wagons and 62 two-horse wagons average approximately 8½ miles per wagon per day; the 64 Worcester retail routes considered in this study aggregate 565 miles, 8.83 miles per route. Eight and one-half miles is probably a conservative estimate for approximately 265 milk wagons distributing milk daily in Worcester. The total public street mileage within the city limits is 220, but several miles are practically unoccupied. These milk wagons cover approximately 2,250 miles daily to supply the houses on less than 220 miles of streets. Probably they travel 10 to 14 times the populated street mileage every day.

Duplication of delivery routes is common to all retail business, but in large cities measures have been taken to overcome this waste through central delivery agencies, where the parcels are assembled, sorted and delivered regularly. The system has proved economical but the objections to this method for the delivery of milk are too serious to overcome, except by the establishment of a co-operative milk plant.

9. Another economic waste generally overlooked, common to other commodities as well as milk, is shipping to other markets than the local one. Why should Worcester, the center of one of the finest dairying sections, draw on Maine for its milk supply, when milk produced in the vicinity of Worcester is shipped to Boston? Other things being equal, the local market is the best market. Long-distance shipments are expensive to some one, and cause shrinkage and deterioration in quality. The producer in Massachusetts is in the very favorable position of having his market at his very door, yet he frequently seeks one further afield at necessarily increased cost to the consumer or a smaller return to him.

Suggestions for improving Conditions.

1. Keeping adequate accounts to show cost of operation and calling attention to wasteful methods and inefficiencies. A little study will show many leaks which can often very easily be stopped.

2. Standardizing distribution. The data indicate the need of determining what is adequate and efficient equipment for a 500, 800 or 1,200 quart delivery. Is a two-horse load with one driver and a helper or the one-man, one-horse unit the more economical? None of these things has been worked out.

To answer these questions completely means standardizing the milk-distributing business; the answer will indicate means of eliminating waste, lessening costs and increasing service. Many such studies as this must be made but even this first one indicates some points of attack. Not only should the individual distributor study his business, but organizations of distributors should be formed in each town and city for mutual improvement and the discussion of points of economy, and for agreement on some division of territory to lessen duplication of routes and to protect their mutual interests.

3. The introduction of the ticket system to lessen collection costs and save time in delivery. The investigation indicates that the use of tickets tends to eliminate loss of bottles and bad accounts.

4. Large daily deliveries per horse and per driver. Several progressive firms in cities not here considered give a bonus to the driver for all deliveries and collections, and a commission on all new business above a certain minimum. This makes it an object for the driver to increase his sales, stop at a few more doors, obtain new customers and climb additional stairs. Long hauls from farm to delivery district are costly and the longer the initial haul the more milk deliveries necessary in order that this high initial cost may be offset.

5. Co-operative delivery. But, after all is said, the final adequate solution of milk distribution will come only through municipal delivery or the organization of producing distributors. In small cities and towns a co-operative milk plant, owned and managed by dairymen, is very feasible. One plant could easily process and deliver the necessary 2,500 to 10,000 quarts per day and solve most if not all of the problems of economical and adequate supply.

6. Central milk plants. The problem of milk distribution in large cities is difficult but the organization of the small milkmen operating in one section of a city into a distributing agency would cure many ills and bring about cheaper delivery. Organization of selling is an old matter to manufacturers and merchandisers but not to dairymen. The difficulties are personal, but sometimes personal jealousies and suspicions are fatal to progress and profits.

The solution of the milk problem is in the hands of the milk producers and dealers. If they have sufficient courage, foresight, perseverance and determination to organize for the study of their own business and the efficient disposal of their own product, all concerned will benefit.

The dairymen supplying a large percentage of the milk of Erie, Pa., have owned and operated their own plant for years. They handle milk, cream and ice cream and not only distribute an excellent quality of milk at low cost, but turn over to the producer a much larger percentage of the consumer's price than he ordinarily obtains. Their success commends their methods to the attention of progressive distributors.

They point to the following achievements: (1) a pure milk supply with an amazingly low bacterial count; (2) a lower price than in many other cities; (3) elimination of duplicate routes, resulting in (4) large deliveries per horse and driver; (5) concentration in large and convenient plants; (6) economical disposal of surplus milk by means of a condensery which the association operates; (7) better wages to employees and (8) satisfactory prices to the producers; (9) practical elimination of the difficulties which usually arise between producer and dealer; (10) no wasteful competition and (11) not a cent paid either in interest or dividends to the original shareholders; (12) every cent of net receipts has gone to the producers, to the plant or to a reserve fund.

Not only this, but this method places the distribution on such a basis that the town authorities could supervise the supply at a minimum cost by co-operating with other towns similarly situated. The cost of upkeep of a laboratory for a chemist and inspector in a small town is prohibitive at present, but if borne jointly by several towns the expense would be reduced to a figure well within their means. The advantages obtained by milk inspection are too well known to need consideration here.

BULLETIN No. 174 NOVEMBER, 1917

MASSACHUSETTS
AGRICULTURAL EXPERIMENT STATION

THE COMPOSITION, DIGESTIBILITY AND FEEDING VALUE OF PUMPKINS

By J. B. LINDSEY

This bulletin contains a detailed report on the composition, digestibility and feeding value of the ordinary field pumpkin. On the first two pages will be found a brief statement of the results secured, together with various suggestions relative to the place of the pumpkin in farm economy.

Requests for bulletins should be addressed to the
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Publication of this Document
approved by the
Supervisor of Administration.

BULLETIN No. 174.

DEPARTMENT OF CHEMISTRY.

THE COMPOSITION, DIGESTIBILITY AND FEEDING VALUE OF PUMPKINS.

BY J. B. LINDSEY.

SUMMARY OF THE RESULTS.

1. The pumpkin contains some 17 per cent. of shell, 73 per cent. of flesh, and 9 to 10 per cent. of seed and connecting tissue. It is a watery fruit, showing extremes of 84 to 91 per cent., with an average of 88 per cent.

2. The whole pumpkin is relatively rich in ash; the seed shows noticeably less ash than the remainder of the fruit.

On the basis of dry matter, the entire pumpkin contains rather more total protein than is found in grains and roots. It also contains some 18 per cent. of total sugars, of which one-third was found to be present in the form of cane sugar. The fruit minus the seeds contains nearly 43 per cent. of total sugars, which explains in a measure its desirability as a human food. The pumpkin seeds are very rich in fat, and are composed substantially of one-third fat, one-third protein and one-fifth fiber, the balance being carbohydrates and ash.

3. A number of digestion trials were made with sheep, and showed the pumpkin to be about 81 per cent. digestible. On substantially the same water basis, and allowing for the increased food value of the fat, the pumpkin appears to have about 20 per cent. greater feeding value than mangels and turnips.

4. Feeding experiments were made with dairy cows, substituting in the ration 30 pounds of cut pumpkins for 5 pounds of hay. The results secured indicated that 5 to 6 pounds of pumpkins were equal in food value to 1 pound of hay. The Vermont station concluded that 2½ pounds of pumpkins were about equal to 1 pound of silage, and that 6½ pounds were fully equal to 1 pound of hay. On page 66 will be found the conclusions of other investigators.

The pumpkin had a tendency to increase temporarily the fat percentage in the milk, due evidently to the oil contained in the seed.

5. The seeds appeared to be free from any injurious effects upon the animals when fed in the amounts found in the entire fruit, contrary to the notion prevalent among many farmers. In foreign countries they are often dried and ground, and serve as a very nutritious and harmless food, if not fed in too large amounts.

6. It is not considered good economy to grow pumpkins exclusively as a food for either cows or pigs, because of their high water content and poor keeping quality. For the latter reason it is advisable to feed them in the late fall or early winter. In one instance a yield of 9 tons is reported when they were grown exclusively, on which basis they would yield about 2,000 pounds of actual food material (digestible organic matter plus fat multiplied by 2.2) as against 3,000 pounds derived from corn. Their place in the farm economy seems in a way to have been discovered by the farmer, namely, in their limited cultivation together with corn.

7. They may be fed cut reasonably fine at the rate of 30 to possibly 50 pounds per head daily, in place of 6 to 10 pounds of hay, in addition to hay and a reasonable amount of grain. It is not advised to feed them with other watery foods such as roots and silage.

They also may be fed (cut fine) to pigs, mixed with a combination of equal parts, by weight, of corn meal and fine wheat middlings, or with a mixture, by weight, of 95 parts corn meal and 5 parts of digester tankage. It is doubtful if it pays to cook them. If fed in too large amounts daily they furnish too much bulk but insufficient nutriment, and as a result the animals are likely to lose in flesh.

COMPOSITION OF THE PUMPKIN.

The ordinary field pumpkin (*Cucurbita pepo*) is planted more or less by New England farmers, frequently in the field with corn. It is used as a human food, particularly for pies, and is also fed to pigs and to dairy and beef cattle.

Ulbricht and Kosutany[1] have shown that in twelve different varieties of the genus *Cucurbita* the parts were present in the following proportions: —

	Per cent.
Shell,	17
Flesh,	73
Seed,	2
Seed and supporting tissue,	7

The pumpkin is a watery fruit. We have found variations of from 84.08 to 91.18 per cent., with an average of 87.53 per cent. in four lots grown on two farms in two different years. In the pumpkin minus the seeds and connecting tissue variations of from 90 to 94 per cent. were noted, with an average of 92.78 per cent., while the seeds contained from 43 to 47 per cent. The seeds, it will be noted, were much less watery than the other portions of the fruit. It was noted that the ripe pumpkins without the seeds contained 4 per cent. less water than the same material less mature. The riper the fruit and the drier the autumn the higher will be the percentage of dry matter.

Other investigators, including Dahlin,[2] Braconnet,[2] Zeunak,[2] Gerardin,[2] Wanderleben,[2] found in 10 sorts of the entire fruit extremes of from 85.8 to 94.2 per cent. of water, with an average of 90 per cent. Storer and Lewis,[2] with 5 varieties, noted variations of from 84.3 to 94.6 per cent., with an average of 90.41 per cent. Hills[3] found 87.9 and 90.1 per cent. in two lots of field pumpkins.

On the basis of the natural moisture the four lots of the fruit examined by us tested as follows: —

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[1] Landw. Versuchsstationen, 32, p. 231.

[2] After Ulbricht, already cited.

[3] Vermont Experiment Station, fourteenth report, Appendix, p. iv., and sixteenth re
Appendix, p. iii.

A. *Entire Fruit.*

SAMPLE.	Water.	Ash.	Crude Protein.	True Protein.	Amids (N×6.25).	Fiber.	Extract Matter.	Fat.	Reducing Sugars.	Sucrose.
1,	91.18	.67	1.56	1.20	.37	1.49	3.81	1.29	1.43	.80
2,	86.58	1.05	1.90	-	-	1.75	7.28	1.44	-	-
3,	84.08	1.16	2.49	-	-	2.29	8.24	1.74	-	-
4,	88.28	.97	1.74	-	-	1.84	5.67	1.50	-	-
Average,	87.53	.96	1.92	1.20	.37	1.84	6.25	1.49	1.43	.80
B. Without Seeds and Supporting Tissue.										
1,	94.33	.50	.78	.45	.33	.98	3.26	.15	1.67	.32
2,	90.00[1]	.77	1.63	.79	.83	1.22	6.14	.24	2.60	1.89
3,	94.00[2]	.38	1.09	.33	.76	.98	3.43	.12	2.14	.57
Average,	92.78	.55	1.17	.52	.64	1.06	4.28	.17	2.14	.93
C. Seeds.										
1,	43.00[1]	2.34	19.17	17.84	1.33	10.37	3.71	21.41	-	-
2,	47.00[2]	1.56	15.98	14.51	1.47	11.23	4.41	19.82	-	-
Average,	45.00	1.95	17.58	16.18	1.40	10.80	4.06	20.62	-	-

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[1] Ripe.

[2] Green.

A. Entire Fruit.

SAMPLE.	Ash.	Crude Protein.	True Protein.	Amids.	Fiber.	Extract Matter.	Fat.	Reducing Sugars.	Sucrose.
Average of 4,	7.70	15.40	9.62[1]	2.97[1]	14.76	50.19	11.95	11.47	6.42
B. Without Seeds and Supporting Tissue.									
Average of 3,	7.62	16.20	7.20	8.86	14.68	59.15	2.35	29.64	12.88
C. Seeds.									
Average of 2,	3.55	31.96	29.42	2.55	19.64	7.38	37.49	–	–
D. Roots and Grain for Comparison.									
Carrots (average),	10.26	10.26	–	–	9.40	68.38	1.70	–	–
Mangels (average),	10.64	14.89	–	–	8.51	64.89	1.07	–	–
Corn kernels,	1.50	11.00	–	–	2.20	80.90	4.40	–	–
Wheat kernels,	2.00	13.60	–	–	3.00	79.20	2.20	–	–

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[1] One sample only.

In order to make a fairer comparison of the composition of the dry material, the average results, as shown in table on page 58, have been calculated to a water-free basis, as shown in table on page 59.

The whole pumpkin contains rather less ash than carrots or mangels, although it is much richer in mineral matter than the ordinary grains. The seed is much poorer in ash than the other portion of the fruit. The dry matter of the entire pumpkin contains rather more total protein than roots or grain, with a portion of it in the amido form. The seeds were found to be very rich in true protein. The fiber content of the fruit is noticeably higher than in roots. The seeds have more fiber than the other portion, due to the tough seed coat. Nearly all of the fat is contained in the seed, the analysis of the two samples showing an average of 37.49 per cent. The pumpkin contains large amounts of sugars; in the entire fruit one notes nearly 18 per cent., of which substantially one-third is in the form of cane sugar, while in the portion free from seeds 42.52 per cent. total sugars are noted. While sugar was not determined in the seeds, it is evident that they contain little, being made up chiefly of protein, fat and fiber.

Ulbricht [1] and Hills [2] made analyses of the ordinary field pumpkins, and Zaitschek,[3] of the so-called giant pumpkin (*Cucurbita maxima*), with the following results: —

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[1] Already cited.

[2] Vermont Experiment Station, fourteenth report, Appendix, p. iv., and sixteenth report Appendix, p. iii.

[3] Landw. Jahrbücher 35, p. 245.

	ULBRICHT.				ZAITSCHEK.				HILLS.	
	Entire Fruit.	Entire Fruit, Dry Matter.	Seed less Skin.	Seed less Skin, Dry Matter.	Pulp.	Pulp, Dry Matter.	Seeds.	Seeds, Dry Matter.	Entire Fruit.	Entire Fruit, Dry Matter.
Water,	90.9	-	26.3	-	95.02	-	51.04	-	89.40	-
Ash,	.5	5.5	3.4	4.6	.53	10.55	2.12	4.32	.96	9.04
Crude protein,	1.3	14.3	26.5	35.9	.77	15.44	14.97	30.58	1.50	14.19
True protein,	-	-	-	-	.52	10.49	14.24	29.08	-	-
Fiber,	1.7	18.7	1.2	1.7	.65	13.04	7.81	15.96	1.50	14.11
Extract matter,	5.6[1]	61.5[1]	4.9	6.6	2.82	56.79	6.21	12.68	5.90	55.72
Fat,	-	-	37.7	51.2	.21	4.18	17.85	36.46	.74	6.95
Pentosans,	-	-	-	-	.26	5.17	2.62	5.36	-	-
Calories per 100 grams,	-	-	-	-	20.55	412.40	305.90	624.80	-	-

[1] Including fat.

These figures agree with those secured in this laboratory. They show a high water content in the natural fruit and a relatively high percentage of crude protein. The seed is shown to be particularly rich in protein and oil, and quite low in carbohydrate matter.

DIGESTIBILITY OF PUMPKINS.

A number of digestion trials were made in two successive years, using two sheep in each case. The pumpkins were fed together with hay and also with hay and gluten feed as basal rations. The entire details of the experiment will be published elsewhere. The coefficients of digestibility only are given in the table on page 63.

A. Entire Fruit.

YEAR.	Sheep No.	Hay fed (Grams).	Gluten Feed fed (Grams).	Pumpkin fed (Grams).	Dry Matter digested (Per Cent.).	Ash digested (Per Cent.).	Crude Protein digested (Per Cent.).	Fiber digested (Per Cent.).	Extract Matter digested (Per Cent.).	Fat digested (Per Cent.).
1913–14,	1	550	–	2,000	75.87	64.82	70.50	59.74	81.54	96.29
1913–14,	2	550	–	2,000	89.32	63.93	80.69	86.30	98.12	96.87
1914–15,	1	500	–	2,000	81.62	70.96	67.89	65.20	90.84	89.27
1914–15,	2	500	–	2,000	88.23	62.99	67.20	83.59	96.40	91.76
1914–15,	1	550	150	1,200	78.80	68.35	83.63	47.80	86.30	88.10
1914–15,	2	550	150	1,200	75.41	49.82	82.57	46.23	83.83	84.69
1914–15,	1	412	112	2,000	75.57	76.95	74.81	38.49	83.82	94.23
Average,	–	–	–	–	80.69	65.40	76.61	61.05	88.69	91.60
B. Pumpkins minus Seeds and Supporting Tissue.										
1913–14,	1	500	–	2,000	109.23	105.13	92.55	137.52	108.99	101.44
1913–14,	2	500	–	2,000	93.84	59.48	93 96	95.16	102.44	83 81
Average,	–	–	–	–	101.54	82.31	93.26	116 34	105.72	92.63

One notes wider variations in the digestibility of the different ingredients by the two sheep than are desirable. Thus, there are extremes of from 75.41 to 89.32 per cent. in case of the dry matter; 67.20 to 83.63 per cent. in case of the protein; and still wider variations in the fiber.

The coefficients for the pumpkins minus the seeds and connecting tissue are much higher, and indicate that if the seeds had been removed the animals would have digested practically the entire fruit.

Careful observations failed to note any whole seeds or large portions of seeds in the fæces. It seems evident that in case of sheep No. 1 the pumpkins must have exerted a favorable influence on the digestibility of the hay.

Zaitschek carried out digestion experiments on the Giant pumpkin with two steers, feeding a combination of hay and pumpkins. His results are tabulated below in addition to our own for comparison.

Source.	Numbers of Trials.	Dry Matter.	Organic Matter.	Ash.	Crude Protein.	True Protein.	Fiber.	Extract Matter.	Fat.	Pento-sans.	Energy.
Massachusetts Station (2 sheep), .	8	80.7	-	65.4	76.6	-	61.0	88.7	91.6	-	-
Zaitschek (2 steers), . . .	2	81.4	82.3	72.6	70.3	63.7	67.5	89.4	90.1	68.7	80.1

In spite of the variations in results secured at this station with sheep, our average results agree surprisingly well with those secured by Zaitschek.

Applying the digestion coefficients to the composition of the pumpkin in its natural state, we have the following digestible organic nutrients in 2,000 pounds: —

	Source.	Water (Per Cent.).	Crude Protein (Pounds).	Fiber (Pounds).	Extract Matter (Pounds).	Fat (Pounds).	Total (Pounds).	Total plus Fat ×2.2.	Relative Values.
Pumpkins,	Massachusetts Station,	87.53	29.4	22.4	110.9	27.3	190.0	222.8	100.0
	Zaitschek,	93.89	15.9	12.7	52.0	11.9	92.5	106.8	–
Mangels,[1]	Massachusetts Station,	88.00	20.0	6.0	154.0	–	180.0	180.0	80.7
Ruta baga,[1]	Massachusetts Station,	89.00	20.0	20.0	136.0	2.0	178.0	180.4	80.8

[1] For comparison.

The above data indicate that on the basis of substantially the same water content, 2,000 pounds of pumpkins contain some 9 pounds more of digestible crude protein, 16 pounds more of digestible fiber, 43 pounds less digestible extract matter, and some 27 pounds more digestible fat than are contained in a like amount of mangels. Mangels, then, are richer in carbohydrate matter, but less rich in protein and particularly in fat than is the pumpkin. The pumpkin contains more digestible protein than the ruta baga, about the same amount of fiber, rather less carbohydrate matter and noticeably more fat. On the basis of total digestible nutrients, allowing for the increased energy value of the fat, the two roots appear to have about 20 per cent. less feeding value than the same weight of pumpkin. These figures, of course, cannot be taken too literally. It is doubtful if the computation of net energy values — because of the scantiness of the data — would throw any additional light on the relative values of the several feeds.

FEEDING EXPERIMENTS WITH PUMPKINS.

A number of experiments are recorded relative to the value of pumpkins as a feed for cows and pigs. Hills [1] fed three cows in three periods of fifty-four days each on hay, silage, a grain mixture and pumpkins. During the first and third periods the cows received the hay, silage and grain, and in the second period, hay, silage, grain and pumpkins. Two and one-half pounds of pumpkins with 90.1 per cent. of water were substituted for 1 pound of silage, with apparently like results.

In a second experiment with four cows, feeding pumpkins in the second of three periods at the rate of 40 pounds per cow daily, he concluded that 6½ pounds of pumpkins with 87.9 per cent. water were equal to 1 pound of hay.

French [2] fed six Berkshire pigs that were eight months of age on a ration of wheat shorts and field pumpkins (cooked) with the seeds removed. The experiment covered five periods of eighty-four days each, and in the last two periods the pigs consumed an average each of 26 pounds of pumpkins per day. The average daily gain in live weight was 1.5 pounds, and the results were considered quite satisfactory.

Burkett [3] fed several lots of three pigs on combinations of skim milk, corn meal and pumpkins cooked and uncooked; also on milk and raw pumpkins *versus* milk and corn meal; and on milk, pumpkins and apples, half and half, cooked, *versus* milk, corn meal and bran, half and half. The general conclusion was that cooking did not increase the feeding value of pumpkins, and that a combination of skim milk, corn meal and pumpkins gave the most satisfactory results.

Pott [4] reports that in England pumpkins are quite generally fed to fattening pigs, together with ground barley and beans; also to milch cows at the rate of 25 to over 100 pounds daily, cut fine and mixed with cut straw; and to fattening cattle as high as 100 pounds daily, preferably cooked. Pumpkins are also fed in Austria to cows, fattening cattle, pigs and horses. Pott states that the claim made that the seeds are injurious is without foundation.

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[1] Already cited.

[2] Oregon Experiment Station, Bul. No. 53, p. 22.

[3] New Hampshire Experiment Station, Bul. No. 66.

[4] Handbuch der tierischen Ernährung, etc., II. Band, pp. 424, 425.

FEEDING PUMPKINS TO MILCH COWS AT THIS STATION.

In order to observe the effect of pumpkins upon the quantity and quality of milk and on the general condition of the animals, two grade Jersey cows were selected and fed with 30 pounds each of pumpkins daily, in addition to hay and grain. The data and plan are as follows: —

History of Cows.

NAME.	Breed.	Age (Years).	Last Calf dropped.	Approximate Milk Yield (Pounds).	Fat (Per Cent.).	Weight of Cows (Pounds).
Samantha,	Grade Jersey.	11	August 25	36.7	4.1	950
Red III.,	Grade Jersey.	9	August 11	23.5	3.9	910

PLAN AND DURATION OF EXPERIMENT.

The two cows were fed in three distinct periods of twenty-one days each, exclusive of the preliminary periods. In the first period they each received a ration of hay, bran and cottonseed meal and hominy meal; in the second period the same ration, excepting that 5 pounds of the hay were replaced by 30 pounds of the pumpkins; in the third period the ration fed was the same as in the first period. The results secured in the first and third periods were averaged and compared with those secured in the second. Five pounds of hay were therefore compared with 30 pounds of pumpkins.

Care of Animals. — The animals were well cared for and turned into a barnyard about eight to nine hours each day. They were fed twice daily; the hay was given sometime before milking and the grain just before milking, while in the morning the grain was given just before, and the hay just after, milking. Water was supplied constantly by aid of a self-watering device.

Character of Feeds. — The hay and grains were of the usual good quality. The pumpkins were grown by one farmer and were the ordinary yellow field variety of different sizes. Most of them were ripe.

Sampling Feeds and Milk. — The hay was sampled at the beginning and end of each period by taking forkfuls of the daily weighing, running the same through a power cutter, subsampling and placing the laboratory samples in large glass-stoppered bottles with proper markings. The grains were sampled daily by placing definite amounts in glass-stoppered bottles, and these bottles properly labeled were brought to the laboratory at the end of each period.

The pumpkins were cut into small pieces before being fed.

The analytical data serving for the digestion experiment also served for this experiment.

Analysis of the Milk. — The milk of each cow was sampled daily for five consecutive days of the last two weeks of each period, the samples preserved with formalin, and the five-day composite sample tested for solids and fat.

Weighing the Animals. — The animals were weighed for two consecutive days at the beginning and end of each half of the period before the afternoon feeding.

Analysis of Feedstuffs.

	Water.	Ash.	Protein.	Fiber.	Extract Matter.	Fat.
Hay,	11.34	5.16	5.14	31.03	45.57	1.76
Bran,	12.45	6.47	15.73	10.27	50.68	4.40
Cottonseed meal,	8.81	6.37	41.63	10.19	25.91	7.09
Hominy meal,	11.24	2.05	10.41	4.48	64.67	7.15
Pumpkins,	84.77	1.14	2.50	2.10	7.77	1.72

Total Feed consumed (Pounds).

Average, Periods I. and III.

NAME.	Hay.	Bran.	Cotton-seed Meal.	Hominy Meal.	Pump-kins.
Red III.,	378	63	42	42	-
Samantha,	504	84	63	84	-

Period II.

NAME.	Hay.	Bran.	Cotton-seed Meal.	Hominy Meal.	Pump-kins.
Red III.,	273	63	42	42	630
Samantha,	399	84	63	84	630

Daily Feeds consumed (Pounds).

Hay + Grain (Periods I. and III.).

NAME.	Hay.	Bran.	Cotton-seed Meal.	Hominy Meal.	Pumpkins.
Red III.,	18	3	2	2	-
Samantha,	24	4	3	4	-

Hay + Grain + Pumpkins (Period II.).

NAME.	Hay.	Bran.	Cotton-seed Meal.	Hominy Meal.	Pumpkins.
Red III.,	13	3	2	2	30
Samantha,	19	4	3	4	30

Estimated Digestible Nutrients in Daily Rations.

Hay + Grain (Periods I. and III.).

NAME.	Protein.	Fiber.	Extract Matter.	Fat.	Total.	Nutritive Ratio.
Red III.,	1.73	3.60	7.63	.53	13.49	1:7.2
Samantha,	2.51	4.86	11.03	.83	19.23	1:7.1
Average,	2.12	4.23	9.33	.68	16.36	-

Hay + Grain + Pumpkins (Period II.).

NAME.	Protein.	Fiber.	Extract Matter.	Fat.	Total.	Nutritive Ratio.
Red III.,	2.16	3.05	8.31	.97	14.49	1:6.2
Samantha,	2.95	4.31	11.71	1.27	20.24	1:6.4
Average,	2.55	3.68	10.01	1.12	17.36	-

The above nutrients were estimated on the basis of actual analysis and the application of average digestion coefficients. The 30 pounds of pumpkins fed contained 1 pound more digestible nutrients than 5 pounds of hay. This was due to the fact that the pumpkins had rather less water than was expected, and that they contained such a high percentage of digestible matter. On the basis of digestible matter, 1 pound of hay is equivalent to some 4½ pounds of pumpkins.

Weights of the Animals (Pounds).

	RED III.			SAMANTHA.		
Period,	I.	III.	II.	I.	III.	II.
Beginning,	915	930	905	1,095	1,153	1,095
End,	948	930	928	1,140	1,148	1,118
Gain or loss,	+33	±	+23	+45	−5	+23
Average,	+17		+23	+20		+23

Gain or Loss for Both Cows.

Periods I. and III. (hay+grain) = 37 pounds+.

Period II. (hay+grain+pumpkins) = 46 pounds+.

There seems to have been very little difference in the changes in weight as a result of feeding the two rations.

Total Yield of Milk Products.

Hay+Grain (Period I.).

NAME OF COW.	Total Milk (Pounds.	Daily Milk (Average).	Total Solids (Pounds).	Total Fat (Pounds).	Average Per Cent. Total Solids.	Average Per Cent. Fat.
Red III.,	364.4	17.4	47.88	17.49	13.14	4.80
Samantha,	532.1	25.3	76.73	29.11	14.42	5.47

Hay+Grain (Period III.).

Red III.,	301.6	14.4	42.07	16.47	13.95	5.46
Samantha,	460.0	21.9	69.18	26.40	15.04	5.74

Hay+Grain+Pumpkins (Period II.).

Red III.,	341.7	16.3	48.15	19.24	14.09	5.63
Samantha,	495.3	23.6	76.08	29.87	15.36	6.03

Total Yield of Milk Products — Concluded.

Hay + Grain (Average, Periods I. and III.).

Name of Cow.	Total Milk (Pounds).	Daily Milk (Average).	Total Solids (Pounds).	Total Fat (Pounds).	Average Per Cent. Total Solids.	Average Per Cent. Fat.	Average Per Cent. Solids not Fat.
Red III.,	333.0	15.9	45.09	17.08	13.54	5.13	8.41
Samantha,	496.1	23.6	73.08	27.83	14.73	5.61	9.12
Average,	414.6	19.7	59.09	22.46	14.25	5.42	8.83

Hay + Grain + Pumpkins (Period II.).

Red III.,	341.7	16.3	48.15	19.24	14.09	5.63	8.46
Samantha,	495.3	23.6	76.08	29.87	15.36	6.03	9.33
Average,	418.5	19.9	62.12	24.56	14.84	5.87	8.97

The yield of milk was substantially the same on each ration. The total solids showed an increase as a result of feeding the pumpkins, and this was due evidently to an increase in the percentage of fat in the milk. Attention has been called to the fact that the pumpkin seeds are rich in fat. By referring to the average daily rations consumed (page 69) it may be seen that the ration without pumpkins contained .68 pound daily of digestible crude fat, and with the pumpkins 1.12 pounds, the excess of .44 pound of pure fat being derived from the pumpkin seeds. This additional food fat evidently temporarily increased the fat in the milk.

In so far as the results of a single experiment with two cows are concerned it appears that 6 pounds of pumpkins fully replaced 1 pound of hay. On the basis of digestible nutrients our calculations show that 4½ pounds of pumpkins with 84.8 per cent. of water replaced 1 pound of hay with 11.34 per cent. of water. It is quite possible that 25 pounds of pumpkins would have replaced 5 pounds of hay with equal results. Because of the rather wide variations in the moisture content of the fruit, one could say only on the basis of results secured, that from 5 to 6 pounds of pumpkins were equivalent to 1 pound of first-class cow hay.

BULLETIN No. 175 MAY, 1917

MASSACHUSETTS
AGRICULTURAL EXPERIMENT STATION

MOSAIC DISEASE OF TOBACCO

By G. H. CHAPMAN

This bulletin deals with the mosaic disease of tobacco, including a brief review of the work of previous investigators. It also gives results obtained at this station relating to the cause, reaction and control of the disease. It is shown that more than 80 per cent. of field infection may be traced originally to the seed bed. Specific methods for control are recommended.

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Publication of this Document
approved by the
Supervisor of Administration.

BULLETIN No. 175.

DEPARTMENT OF BOTANY.

MOSAIC DISEASE OF TOBACCO.[1]

BY G. H. CHAPMAN.

INTRODUCTION.

The observations and conclusions reported in the following pages are the results of several years of more or less continuous investigation on the part of the writer, and deal with the probable causes, occurrence, appearance and methods of control of this well-known disease of tobacco and related plants. Enough has been accomplished so that it is believed wise to add still another paper to the already long list of literature which has been published on this disease. During the time in which these experiments have been in progress much new literature has appeared dealing with this subject, some of which has helped the writer by verifying his results and by bringing out new facts concerning the disease; but, on the other hand, some of the work appears to have been done in a hasty manner, and possibly erroneous conclusions drawn in some cases, thus adding to the large amount of confusing subject-matter which has to do with this disease. The experiments carried on by the writer were begun in a general way in 1907, and have been repeated several times during the years subsequent to that date, new lines of investigation both in the field and laboratory having been added as occasion demanded. Some considerable time has been spent in verifying the results obtained by other recent investigators, and an attempt has been made to gather together in a broad, general way, as well as in detail, all the reliable information possible about this interesting disease, as well as to bring out new facts in regard to it. More attention has been given to the biochemical aspects of the problem than has heretofore been done by investigators.

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[1] Also presented in part to the faculty of the graduate school of the Massachusetts Agricultural College, June, 1916, as a major thesis in partial fulfillment of the requirements for the degree of doctor of philosophy.

HISTORICAL SUMMARY.

In the following paragraphs is given a brief résumé of the more important work done on the mosaic disease of tobacco up to the present time, and as an excellent critical review of the literature, etc., up to 1902 is given by A. F. Woods [1] in his work on the subject, the same is quoted in full below. He states: —

> Adolph Mayer [2] was the first to make a careful study of the trouble. He demonstrated that it could not be caused by an insufficient supply of mineral nutrients. He found as much nitrogen, potassium salts, phosphates, calcium and magnesium present in the soils and plants where the disease occurred as in the soils where the disease did not occur. He also found that the trouble was apparently distributed over the field without regard to the soil conditions.
>
> Since tobacco requires much lime, liming the soil was tried, but the disease was not prevented thereby. Mayer further kept hotbeds in some cases rather moist, in others dry, and then again, richly or poorly manured with nitrogen; but in no case could he determine that the conditions in question caused the disease. He also found that variations in the temperature of the hotbeds apparently had no effect; neither did crowding, which produced partial etiolation, appear to have any effect on the disease. Seeds from flowers in which self-fertilization was prevented he found to be just as susceptible to the disease as seeds produced without such precautions, but on the soil on which the disease had once appeared it was again produced. According to his observation, also, the trouble was not often found on soil used for the first time for tobacco. He further proved that the juice of the diseased leaves injected with the juice of healthy plants did not develop the disease. He was not able to produce it by injecting diseased juice into other solanaceous plants. Where the diseased juice was injected into tobacco the same trouble developed in from ten to eleven days. Heating to 60° C. did not destroy the infectious substance; at 65° to 75° it was attenuated, and at 80° it was killed.
>
> After Mayer had shown the absence of animal and fungous parasites he supposed bacteria to be the cause of the disease, but all his efforts with bacteria cultivated from the surface of diseased leaves, and also with different mixtures of bacteria, failed to produce it. Nevertheless, he thought that there must be certain pathogenic bacteria present in those soils in which the disease appeared, and therefore proposed to change the soil in the hotbeds and to devote the fields where tobacco had been cultivated to other crops. He also recommended the use of mineral rather than organic manures.
>
> These general results were confirmed by several subsequent investigators. Not, however, till Beijerinck [3] took hold of the question was much of importance added to our knowledge of the malady. He proved the absence of bacteria in the development of the disease. He showed that the juice of the plant filtered through Chamberland filters, while remaining perfectly clear and free from bacteria, still retained the power of infection. A small drop of it injected hypodermically into the growing bud was sufficient to give the plant the disease. He found that only dividing (meristematic) cells can become diseased. Diseased tissue kept its infectious qualities even after drying, and retained its injurious properties in the

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[1] Woods, A. F.: Observations on the Mosaic Disease of Tobacco. U. S. D. A., Bur. Plant Ind., Bul. No. 18 (1902).

[2] Mayer, Adolph: Über die Mosaikkrankheit des Tabaks. Landw. Versuchsstation, 32: 451–467 (1886). Review of the same article in Journ. of Mycology, 7: 382–385 (1894).

[3] Beijerinck, M. W.: Verhandelingen der Koninklijke Akademie van Wetenschappen te Amsterdam. Deel 6: No. 5. See also Centb. f. Bakt., Par., etc., II: 5: 27–33 (1899).

soil during the winter. Weak solutions of formalin did not kill the virus, but heating to boiling point did. Fresh, unfiltered juice was more effective than an equal amount of filtered juice. He found that soil around diseased plants may infect the roots of healthy plants, but he did not determine whether direct transference is possible through healthy root surfaces, or whether insects, by injuring the roots, favored infection. He defines the milder form of the disease as a suffering of the chlorophyll bodies. Later a general disease of the plasmatic contents of the cells sets in.

In field conditions as a final stage the swollen green areas become marked with small dead spots, but these did not appear on plants grown under glass. Under certain conditions he observed that plants apparently recover from the disease; *i.e.*, the new growth appeared to recover. He found that the infective material, whatever it might be, could be transported through considerable distances in the plant, but could cause the disease only in the dividing cells. He assumed the virus to be a non-corpuscular, fluid-like material, which had the power of growth when in contact, in a sort of symbiotic way, with the growing cells, — "a living fluid contagium."

Shortly after Beijerinck's paper, Sturgis[1] published a critical review of the work done on the disease up to that time, with numerous valuable results and observations made in Connecticut, where the trouble is known as "calico" or "mottled top."

The results obtained by Sturgis and observations made by him on tobacco in Connecticut bore out the statements of other careful and critical workers, and greatly cleared up the field for further investigation. He came to the conclusion that on close, clayey soils the disease may be more abundant than on an open, porous soil. The disease is not contagious, but he could not state definitely as to its infectiousness; it is not caused by fungi, nematodes or parasitic insects, and the facts observed by him were not favorable to the theory of bacterial origin. He also came to the conclusion that the disease is not inherent in the seed, and looked upon it as a purely physiological trouble brought about by sudden interruptions of the normal plant metabolism. Koning,[2] in his work, verified much of the work of Beijerinck and Mayer, and Woods[3] later verified the work of these investigators and pointed out that in the diseased leaves there was an excess or excessive activity on the part of an enzyme belonging to the oxidases, and that the power of oxidation in the cells was inversely proportional to the amount of chlorophyll present, using the color as a basis of comparison. He also pointed out that there was a marked structural difference between the cells of the dark green and light green areas, and proved to his own satisfaction that the light green areas are the truly diseased portions, a fact that will be referred to later in this paper. In a later careful investigation of the disease Woods[4] arrived at the following conclusions, which were a great stride forward in our understanding of some phases of this baffling disease. He states: —

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[1] Sturgis, W. A.: Mosaic Disease of Tobacco. Conn. Agr. Exp. Sta. Rept., 250-254 (1898).

[2] Koning, C. J.: Die Flecken oder Mosaikkrankheit des hollandischen Tabaks. Zeitschrift für Pflanzenkr., 9: 65-80.

[3] Woods, A. F.: Inhibiting Action of Oxidase on Diastase. Science, n. s., No. 262, 17-19.

[4] Woods, A. F., *loc. cit.*

The disease is not due to parasites of any kind, but is the result of defective nutrition of the young dividing and rapidly growing cells, due to a lack of elaborated nitrogenous reserve food accompanied by an abnormal increase in the activity of oxidizing enzymes in the diseased cells. The unusual activity of the enzyme prevents the proper elaboration of the reserve food, so that a plant once diseased seldom recovers. On the decay of the roots, leaves and stems of both healthy and diseased plants, the enzyme in question is liberated and remains active in the soil. The enzyme is very soluble in water and appears to pass readily through plant membranes. If the young plants take it up in sufficient quantity to reach the terminal bud, they become diseased in the characteristic way. Under field conditions there is little danger from infection in this manner, but in the seed bed the danger is much greater on account of the greater susceptibility of the young plants to the disease, and the greater amount of free oxidizing enzymes likely to be in the soil due to the decay of the roots and plants. New or steam sterilized soil should therefore be used for the seed bed.

I have shown that transplanting, especially when the roots are injured, may produce the disease. Great care must, therefore, be taken not to injure the roots in this process or in the subsequent cultivation, or to check the growth of the plants.

There is evidence that rapid growth, caused by too much nitrogenous manure or too high a temperature, is favorable to the disease. Why this should be the case has not been determined. It is probably connected with the manufacture of reserve nitrogen by the cells and its distribution to the rapidly growing parts.

Plants grown under such conditions are less able to stand successfully marked variations in temperature and moister conditions of soil and atmosphere. Variations of this kind favor the development of the disease in the less resistant plants.

Close, clayey soils, packing hard after rains and requiring constant tillage, are not favorable to the even growth of either the tops or roots of tobacco plants. In moist, cloudy weather the plants will grow too fast, and in hot, dry weather the soil is likely to bake, checking growth and making probable injury to the roots in cultivation. Such soils are very favorable to the development of the mosaic disease, as pointed out by Thaxter.[1] He found that loosening the soil by liming and giving partial shade, thus causing a more even condition of growth, very greatly reduced the disease.

Crops grown under cheesecloth covers protected at the side are said to be remarkably free from the disease. The plants make a steady rapid growth, much greater than in ordinary field culture. . . .

The disease is not, so far as observed, produced by a lack of soil nutrients, though from its nature we would expect that a deficiency of nitrogen, phosphoric acid, lime and magnesia might favor its development. Koning[2] says that manuring with kainit and Thomas slag diminishes the extent of the disease. Mayer, Beijerinck and other investigators, however, agree that the trouble is not caused by the lack of any soil nutrients. It appears, so far as my own investigations go, that the trouble cannot be cured by giving the plants additional food of any kind. Overfeeding with nitrogen favors the development of the disease, and there is some evidence that excess of nitrates in the cells may cause an excessive development of the ferments that cause the disease. Very slight attacks of the disease known as "mottled top" are said not to injure the quality of the leaf to a sufficient extent to be noticeable commercially, though they may be less elastic and have a poorer burn and aroma than healthy leaves.

Hunger,[3] in his work on the mosaic of Deli tobacco, verified much of the work of previous investigators, and later, in carefully planned and executed experiments,[1] proved that the disease was not contagious but was highly infectious. He believed that it could be carried from diseased to healthy leaves simply by touching, especially in the case of the young leaves, a fact that makes it necessary for the workman to use great care when looking for the tobacco bud worms, etc., in the buds. He was of the opinion that a rupture of the leaf was not necessary to induce the mosaic disease in plants.

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[1] Thaxter: Conn. Agr. Exp. Sta. Rept., III, 253 (1899).

[2] Koning, C. J., *loc. cit.*

[3] Hunger, F. W. T.: De Mozaiek-ziekte bij deli Tabak. Med. s'Lands Plantentium, Batavaia. Deel 1: 63 (1903).

Selby[2] a year later showed this to be apparently true for tobacco grown in Ohio, and Hunger's statements were in his opinion in all respects confirmed. He also reported that "Blossoms of various plants were inoculated through the nectar by transmission of nectar from diseased plants, as by insect visitation. A slender brush of horse hair was used for this purpose. No evidences of the disease were observed as a result of this method."

Clinton[3] was able to produce the trouble on tomatoes by inoculating with juice from a diseased tobacco plant and from the tomato so infected was able to reproduce the disease on the tobacco again by inoculation from the tomato, again showing the infectious nature of the disease, and that the troubles on the tomato and tobacco were practically identical. This has been repeatedly verified by the writer and many other investigators.

Jensen,[4] in his work on the disease, came to the conclusion that the right way to get at the methods of control of the disease was by experimentation to obtain a resistant strain of tobacco, no matter what the cause of the disease might be, and he carried on some experiments along these lines. As yet no definite results have been reported by the investigators, but the time has probably been too short to obtain results.

Lodewijks[5] stated that by subjecting diseased plants to different colored lights he was able to bring about a cure in some cases. He states: —

> The mosaic disease cannot be diminished or prevented by lessened light intensity. Neither diffused nor colored light has any effect on the disease if the healthy leaves are not able to function in normal daylight. Under the latter condition, however, diffused light exerts a retardation, red light diminishes the trouble, and blue light effects a cure. All the results may then be explained by the hypothesis that the virus formation diminishes with the intensity of the light, while in the healthy leaves, through the action of the virus, an anti-virus is formed, the action of which destroys the virus (immunity and antitoxin formation in the case of animals). . . .
>
> Normally in the metabolism of the tobacco plant a substance is formed, the action of which is opposed to that of the equally normally occurring virus of mosaic disease, perhaps because it binds itself chemically to the latter.

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[1] Hunger, F. W. T.: Die Verbreitung der Mosaikkrankheit infolge der Behandlung des Tabaks. Centralbl. f. Bakt. Par., etc., II: 11: 405–408 (1908).

[2] Selby, A. D.: Tobacco Disease. Ohio Agr. Exp. Sta. Bul. No. 15, 88–95 (1904).

[3] Clinton, G. P.: Notes on Fungous Diseases, etc. Conn. Agr. Exp. Sta. Rept., 1907–08, 857–858.

[4] Jensen, H.: Über die Bekampfung der Mosaikkrankheit der Tabakpflanze. Centralbl. f. Bakt. Par., etc., II: 15: 440–445 (1906).

[5] Lodewijks, T. A., Jr.: Zur Mosaikkrankheit des Tabaks. Rec. Trav. bot. Neerlandais, VII. (1910).

> Both substances, virus and anti-virus, may be increased by external factors or conditions. In the first instance the plants become diseased with the mosaic disease; in the latter an immunity against the disease is brought about. Decrease in intensity and cure occur if the virus formation ceases or stops, while at the same time the formation of an anti-virus is taking place normally or is increased.[1]

A discussion of Lodewijks' work is to be found later in this paper.

Allard[2] in a recent work on the disease states that from the results of his experiments he is of the opinion that the trouble is not primarily physiological but is parasitic in nature, but he is unable to throw any light on the nature of the parasite, and in spite of the conclusions drawn by him, none of his results, at least in so far as the writer is able to judge, has in any way weakened the theory that the trouble may be physiological in nature; and some of his results, from the writer's point of view, seem to substantiate this idea of a physiological agency. Two points of great interest are brought out by him, viz., the mosaic as affecting the color of the corolla by blotching, etc., and the carrying of the disease by certain aphids. These points have not been noted before. In the following pages some of his work will be taken up in detail in so far as it seems to bear out or refute work done by the writer.

It may be seen from the foregoing résumé that the theory that the disease is physiological in character has been in the past pretty generally accepted, but the identification of the ultimate causes producing the symptoms varies widely with the different investigators. The writer's conclusions with regard to this point are taken up later in this paper.

NAMES.

By right of priority the term "mosaic" is the one which should be applied to this disease. It has, however, many local names, and these sometimes are applied differently to the different manifestations of the symptoms; among them may be mentioned the following: "calico," "brindle," "mongrel," "mottle-top," "string leaf," "frenching," etc. Other terms have also been used, but they do not in all cases apply to the "mosaic" alone, hence they are here omitted. The term "infectious chlorosis" as suggested by Clinton is perhaps best descriptive of diseases of this general character, with "mosaic" as a specific type under this division, there being many other infectious, chlorotic diseases of plants quite distinct from the mosaic type.

DESCRIPTION OF THE MOSAIC DISEASE OF TOBACCO.

Descriptions of the mosaic disease of tobacco have been repeatedly presented, and the disease itself is so well known that there is little need of repetition at this point, but a brief résumé of the salient characteristics of the disease will be given so that no misunderstanding may arise, as several other leaf troubles more or less chlorotic in character have often been confounded with the true "mosaic." The disease may show on the leaves at all stages of the growth, from the seedling to the mature plant. It is often difficult in seedlings to diagnose the trouble definitely, as the slight mottling and curl of the leaves may be due to other factors. As a rule, in young plants the leaf is rougher and a *permanent* mottling is observed, very slight in character, however, and not to be confounded with the mottling due to normal metabolic processes which occurs under certain conditions of growth. As the disease progresses, however, the leaf is found to be divided into light and dark green areas; in mild cases there does not appear to be any marked leaf distortion, and the light green areas sometimes verge on the yellow in color. The dark green areas apparently deepen in color with the intensity of the disease, and in extreme cases the leaf is much distorted and the dark portions appear blister-like, due to their more rapid growth. The leaves, as a rule, are much stiffer and thicker to the touch than are the normal healthy leaves. Sometimes in the later stages of the disease there are found dry, dead, brown patches or spots on the leaves, sometimes where the dark green areas were originally, but more often the light green portions show this extreme condition. Both the light and dark areas show abnormalities in structure; nevertheless, the light green areas are the more truly diseased ones, the dark green areas presenting different characteristics, and although showing changes in cell arrangement, etc., function more normally in many respects. Most investigators have held that the light green areas are the diseased portions of a leaf, but some have been of the opinion that the dark green areas are the diseased portions. As will be seen from the writer's experiments the former is the more correct view, as the increase in color intensity and the blistering of the dark green areas is due to the necessarily increased functioning thrown on these portions of the leaf.

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[1] Translation from abstract of Lodewijks' paper in Bot. Centralbl., 114-518 (1910).

[2] Allard, H. A.: Mosaic Disease of Tobacco. U. S. D. A., n. s., Bur. Plant Ind., Bul. No. 40 (1914).

Occasionally a leaf may be distorted in such a manner as to present the appearance of being little more than a long filament consisting principally of midrib, with but very little leaf surface. This condition has been observed by the writer in some instances, but should not be confounded with a similar trouble occurring on tobacco in certain regions, which is of an unknown character but which is not the true mosaic as it is not infectious. This latter trouble has been noted particularly in Java, etc., as is reported by Peters[1] in his work on the diseases of tobacco. It has not been observed in tobacco fields in this region by the writer.

It is thought that soil and moisture conditions are responsible at least partially for this disease.

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[1] Peters, L.: Krankheiten und Beschadigung des Tabaks. Mitteil. aus der Kaiser. Anstalt F. Land- u. Forstwirtschaft. Heft, 13: 64 (1912).

OCCURRENCE.

The mosaic disease has been known for years both in Europe and America, and may be said to be present everywhere that tobacco is grown. It apparently is a more serious disease in the tropics and in certain parts of Europe than it is in this country. In New England it has been known for some time, and, although present to a certain extent each year, is not of such great economic importance as in some other localities. In Massachusetts it is found practically everywhere, and some years appears to be much more prevalent over widespread areas than in others. As a rule, however, the disease is not epidemic in character, and often only a comparatively few plants in a field will be found affected.

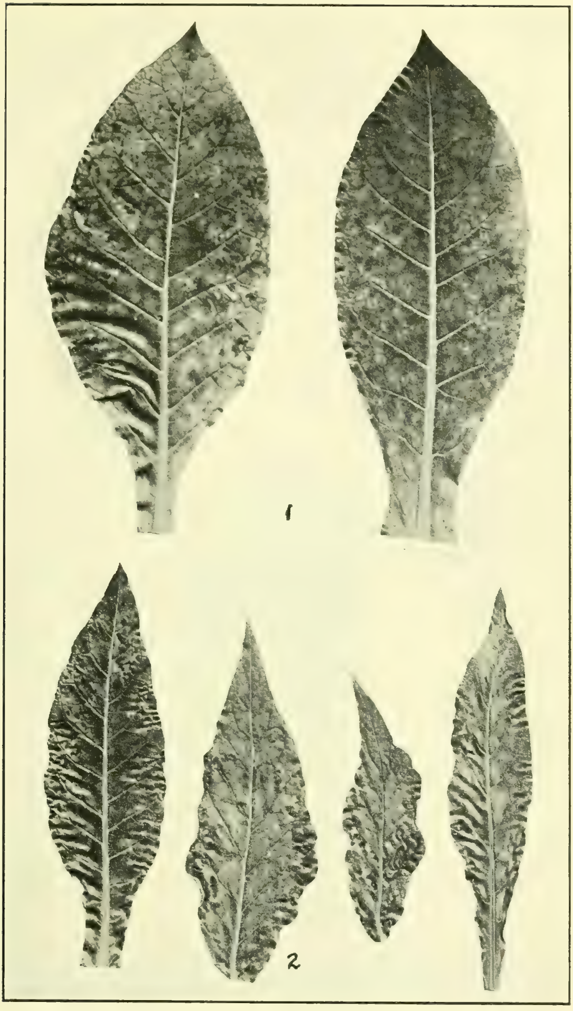
On certain fields, however, — and these most often are such as have been cropped to tobacco for many years without the practice of cover-cropping or rotation, — mosaic disease is present year after year, and a large percentage of the crop is always badly affected, the plants beginning to show the trouble in from three to four weeks after planting in the field.

The prevalence of the disease in the field, aside from the special cases above noted, is apparently related in some way to conditions in the field during the growing season, or during the time the plants are in the seed bed. There is no question that a large percentage of the infection found in the field, exclusive of that appearing on the sucker growth after topping, or due to infection at the time of transplanting, is due to a primary infection from the seed bed.

While the disease as a rule is first noticed in the field some time after transplanting, very often the seedlings in the beds are affected. This is particularly true in the case of old or carelessly treated beds. It is often very difficult for the casual observer to identify the disease on the seedlings, as the macroscopic or visible symptoms are either very slight or lacking. In this way many plants are transplanted to the field by workmen without their being aware that they are diseased, and the disease becoming more pronounced in the later stages of growth, the infection is laid to the soil in the field, when in reality the infected soil of the seed bed is responsible and not the field soil. As has been stated, the closest examination of the seedlings is necessary to identify the trouble in the seed bed, particularly in mild cases of infection.

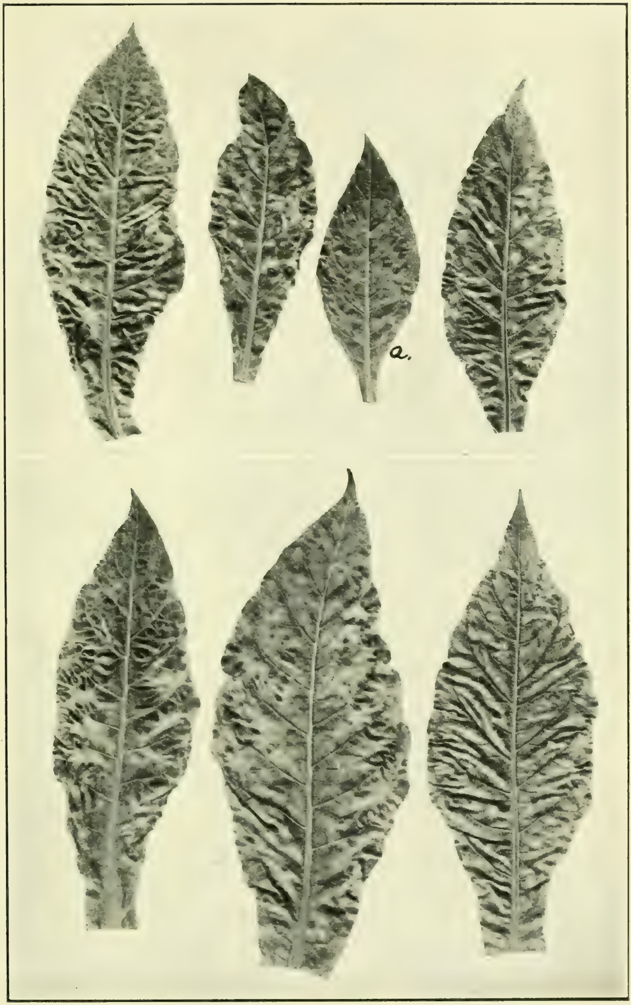
From observations made repeatedly, not only on seed beds but also experimentally under controlled conditions in the greenhouse with soils from old beds, afterwards transplanting the seedlings to soil previously not used for tobacco, and using as checks healthy plants from new soil, the writer has come to the conclusion that at least 80 per cent. of our field infections come from the seed bed and *do not* originate in the field as is commonly supposed.

PLATE I.



Mosaic disease on tobacco leaves. (1) Older leaves showing mottling. (2) Leaves showing marked distortion and tendency to string leaf (on right).

PLATE II.



More or less indistinct types of mosaic disease, except (*a*), which is a young leaf with pronounced blisters.

ECONOMIC IMPORTANCE.

It is very difficult to estimate the loss to growers due to mosaic disease, as the prevalence in different localities varies greatly, as also does the intensity of the attack in different seasons. The damage resulting from mosaic disease is twofold: first the plants when severely attacked are smaller and the leaves poorer in quality; secondly, the buyer, if he sees much mosaic in a field, will invariably cut the price a few cents a pound, as the leaves affected do not in many cases make a valuable wrapper and are much poorer in quality. The writer has observed certain fields where the loss would run into hundreds of dollars from this cause alone. The amount of damage done by late mild attacks when the plants are maturing, or appearing on the sucker growth after topping, is practically negligible, and, so far as can be learned, does not in any way injure the commercial leaf. It is always well to clean off the diseased suckers, however, as they present a very ragged appearance, and might injure the sale of the crop to a certain extent. There is no question but that during certain seasons the loss due to mosaic is quite large, but an exact estimate of this loss is difficult to obtain, owing to the many other factors involved.

INFECTIOUS NATURE OF THE DISEASE.

That the mosaic disease is very infectious is well known, and a discussion of the detailed experiments on this point is not necessary. Experimentally it has been repeatedly shown that the juice from all parts of a diseased plant is capable of transmitting the disease, although it should be stated that the percentage of infection obtained from the root extract is considerably lower than that obtained from the leaves. A few of the results obtained are given in the following table, however: —

TABLE I. — *Infectivity of the Juice from Different Parts of Diseased Plants, August, 1909.*

PART OF DISEASED PLANT USED (PLANTS FROM FIELD).	Number of Healthy Seedlings inoculated.	Number of Plants Diseased Three Weeks after Inoculation.
Leaves showing disease,	10 (juice; needle pricks),	10
Control,	10 (distilled water; needle pricks),	-
Leaves showing disease,	10 (insertion of tissue into veins),	9
Control,	6 (insertion of healthy tissue into veins),	-
Basal leaves (not showing disease),	12 (juice; needle pricks),	10
Control,	5 (distilled water; needle pricks),	1
Roots,	21 (juice; needle pricks),	14
Control,	7 (distilled water; needle pricks),	-
Roots,	16 (insertion of tissue into veins),	6

Later experiments with the roots of other diseased plants gave similar low results.

It is a very easy matter to infect seedlings at the time of transplanting, and the writer has repeatedly seen many cases in the field which could only have been brought about by such infection. It is only necessary to get some of the juice from the diseased plant on to the hands to transmit the disease by handling healthy plants, the causal agent gaining entrance through the broken ends of roots, leaf hairs or broken and abraded leaf areas. In some of the experiments conducted relative to this point, a very high percentage of infection has been obtained. In one case where the juice from a diseased plant was very thoroughly rubbed on the hands, and 40 healthy seedlings immediately set, no care being used to guard against bruising the leaves, etc., 31 plants developed the disease in two weeks' time. In another experiment where 62 seedlings were subjected to the same treatment, 30 plants developed the disease; in still another, series of 28 seedlings, 21 developed the disease. Controls planted at the same time, handled with a hand rubbed with the juice of a healthy leaf developed the mosaic in only a few isolated cases. From the above it can easily be seen that great care should be exercised in the matter of handling the seedlings, especially diseased seedlings.

Contagious Nature of the Disease.

In spite of the fact that it is held by some investigators that the mosaic disease is contagious, the writer has never been able to satisfactorily demonstrate that it is. Under carefully controlled conditions in the greenhouse, guarding against accidental infection, it has been impossible to demonstrate the contagious nature of the disease. In isolated instances, indeed, apparent contagion has occurred, but it is believed that these cases were due to accidental infection, as the percentage was so low, — less than 2 per cent., — and under the conditions the plants were subjected to, such as contact, spraying of the juice on leaves, etc., the percentage should have been much higher if contagion was to be held responsible.

It is a fact that it is only necessary to break or rupture the trichomes or hairs on the leaf, subsequently spraying with diseased juice, to obtain infection, although this method does not give a very high percentage. It can easily be seen that such a rupture may be very easily brought about, and hence apparent contagion occur. As is stated elsewhere in this paper, insect and other carriers may also play a part in these so-called cases of contagion.

Pathological Anatomy.

Leaves.

As might be supposed, there are great differences in structure between normal, healthy leaves and leaves affected with the mosaic disease. These differences are greatest, naturally, in badly diseased leaves. Woods[1] was one of the first to point out this fact, and his statements have been repeatedly verified by the writer. He stated that the light colored areas were not normal, and that "this difference consists in the fact that in badly diseased plants the palisade parenchyma of the light colored areas is not developed at all. All the tissue between the upper and lower epidermis consists of a spongy or respiratory parenchyma rather more closely packed than normal. In moderately diseased plants the palisade parenchyma of the light area is greatly modified. Normally the palisade parenchyma cells of a healthy plant are from four to six times as long as broad. In a moderately diseased plant, however, the cells are nearly as broad as they are long, or at most, not more than twice as long as broad. As a rule, the modified cells of the leaf pass abruptly into the normal cells of the green area."

From the above it can be seen that Woods was of the opinion that the light green areas were abnormal or diseased, and that the dark green areas were normal and healthy. The writer in his observations found this to be true in general, but occasionally the dark green areas showed a more closely packed parenchyma than in normal leaves, and *always the palisade layer was well developed* and approached the normal in character. The development or non-development of the palisade layer, as Woods hinted, is dependent on the degree of severity of the disease. The lighter the attack the less are the palisade cells and parenchyma tissue altered, and *vice-versa*. This the writer found to be true in so far as anatomical differences were concerned, but as will be noted later, the dark green, apparently normal, healthy tissue contained some of the infective agent of the disease.

The structure of the dark green areas varies only slightly from that of the normal leaf, with the few exceptions above noted, and may be considered normal in character. The writer has sectioned many leaves in all stages of disease, and these structural differences have always been found to occur in the manner above indicated. These differences in structure have been taken up more or less in detail, as some investigators have held, and still hold, that the dark green areas are the part diseased, and that the light green areas are normal, inasmuch as they approach the normal leaf in color in many cases, most probably basing their assumption on the fact that the dark areas form blister-like growths and are sometimes darker in color than normal leaves. No one recently appears to have investigated the structure of the dark and light areas carefully in the case of the tobacco, except Woods. It was to verify Woods' statements that the writer took up this phase of the matter, and mention will again be made of it in connection with the biochemistry of the leaf. There can be no doubt as to the correctness of Woods' contention that the light green areas are abnormal and diseased; but that the dark green areas are not diseased, at least in certain cases, cannot be so definitely stated. Their structure may be somewhat modified by the increased functioning thrown on the healthy cells. On the other hand, it is fallacious to state that the light green are the healthy, and the dark green are the diseased, portions of a leaf.

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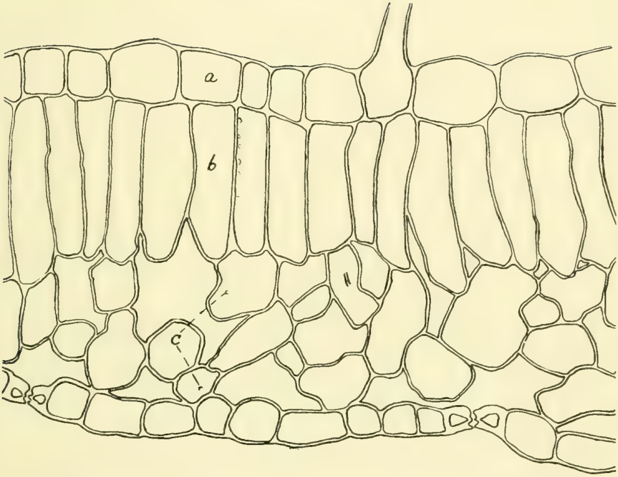
[1] Woods, A. F.: Inhibiting Action of Oxidase on Diastase. Science, n. s., XI., No. 262, 17–19 (1900).

Plates III. and IV. show three cross sections from leaves, III. showing the cross section of a healthy leaf; IV., that of the light green area of a diseased leaf and of a dark green area of the same leaf. It will be noted that the palisade layer is practically suppressed in IV. (1), or the light green portion, while in IV. (2) the palisade layer approaches the normal in character except for a closer packing of cells in general. Milder cases of diseased leaves vary between these limits. These figures are from *camera lucida* drawings of material killed and fixed in medium chrom-acetic acid. In the material used the normal leaf section is somewhat thicker than those of the diseased leaf, but for comparative purposes is perfectly satisfactory.

Stems.

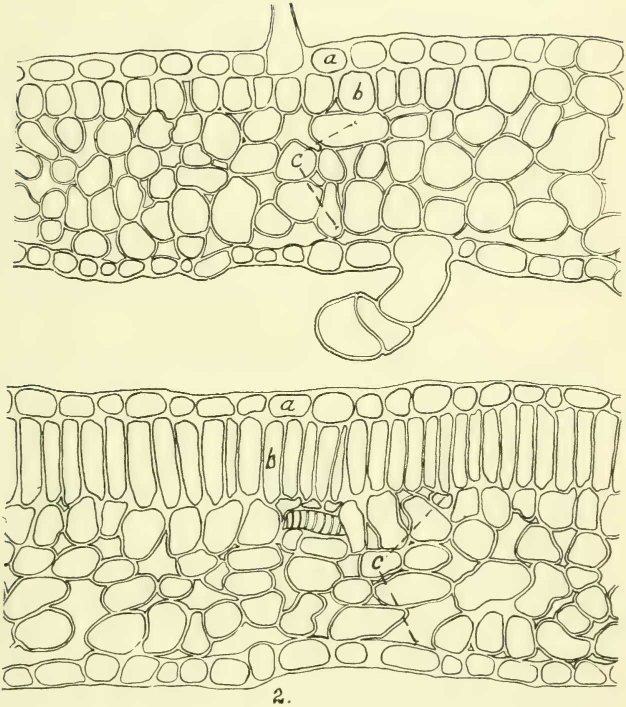
The anatomical differences in the leaves of healthy and diseased tobacco plants have been given in the preceding paragraphs, and as it was desired to carry the investigations further to cover the entire plant, repeated examinations were made of both cross sections and longi-sections of stems of plants in various stages of disease, and also of healthy, normal plants grown both in the field and greenhouse. It should be stated at this point that occasionally the writer has observed on the stems of some badly mosaicked plants a mottling, or, rather, a streaking of the stem, a portion of which would be darker green than the remainder, and this is without question a manifestation of the mosaic disease. Sections of such stems, however, showed absolutely no variation in structure from those of normal plants, and in no case, although the examinations covered an extended period of time, was it possible to show any structural difference between the stems of badly diseased mosaic plants and those of healthy plants of the same age. Examinations of the stem close to the terminal apex of the plant revealed the same conditions as those of other parts of the stem. No differences were observable except in the matter of size and arrangement of cells, such as would naturally be expected when we take into consideration the differences in size and development of the stem near the terminal apex and progressively towards the base.

PLATE III.



Section through normal tobacco leaf: (*a*) epidermis; (*b*) palisade cells; (*c*) parenchyma tissue.

PLATE IV.



Sections through mosaic-diseased leaves. (1) Light green area: (*a*) epidermis; (*b*) palisade cells; (*c*) parenchyma tissue. (2) Dark green area: (*a*) epidermis; (*b*) palisade cells; (*c*) parenchyma tissue.

Roots.

In the same manner roots of mosaicked and healthy plants were examined at various times under all conditions of growth and severity of disease, and in every case the root structure was found to be normal. Root tips from healthy and diseased plants showed absolutely no differences in structure. It might be anticipated that, as the disease first manifests itself in the dividing cells of the leaves, there might be a supplementary differentiation, so to speak, of the meristematic tissue at the growing point of the root, functioning co-ordinately with that of the aerial part of the plant. No such condition was observable, however, and, so far as the writer has been able to find, there is no manifestation of local cell disturbances in the root such as are found in the leaf tissue.

The causal agent of the disease, however, as has previously been noted, is without question present *in all parts of the plant,* and it should not be stated that it is confined to those parts which show structural variation.

Fungi and the Mosaic Disease.

Almost from the first it has been established that no fungi are associated with the cause and development of the mosaic disease of tobacco. In no case where careful work has been conducted under conditions eliminating the possibility of accidental infection has any fungus been found associated with the trouble. Cultures of fungi obtained occasionally from leaves have always been traceable to careless manipulation or external infection, and the fungus obtained failed to infect healthy plants, no matter what methods of inoculation were used.

The writer has occasionally obtained cultures on various media such as oat agar, tobacco leaf agar and prune agar, from the tissue of the so-called "rusted" spots which are sometimes a late manifestation of the last stages of the mosaic; but, as with previous investigators, it was found impossible to infect healthy plants from these cultures, either by needle pricks, spraying, or inserting the fungus into incisions in the leaf or stem.

These experiments with fungi were made merely to demonstrate to the writer's own satisfaction that they could not be the causative agents of the disease, as there might be a possibility that they were latent in the plant during the earlier stages of the disease and only developed superficially during the later stages.

According to Jenkins[1] and others these rusted spots which are sometimes observed are primarily caused by a drying out and disintegration of the cell tissue, which has been weakened by the disease and which thus forms a suitable medium, under favorable conditions, for the development of secondary fungi and micro-organisms. This view is also held by the writer as a result of observations extending over a series of years.

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[1] Jenkins, E. H.: Studies on the Tobacco Crop of Connecticut. Conn. Agr. Exp. Sta. Bul. No. 180, p. 56 (1914).

BACTERIA AND THE MOSAIC DISEASE.

Among the many theories advanced regarding the cause of the mosaic the chief one for some time, particularly among the earlier investigators, was that of bacterial infection either through the agency of infected soil or otherwise. Mayer,[1] in his rather extended study of the disease, came to the conclusion that it was caused by bacteria, but was unable to isolate the organism. Prilleux and Delacroix[2] claimed to have found an organism associated with the mosaicked leaves, but their descriptions leave one in doubt as to whether they were working with the true mosaic disease or not. It is very probable that they were dealing with another disease which occurs in France, but which is somewhat different from the mosaic disease. The next important work on the bacteria supposedly connected with this disease was done by Iwanowski.[3] He isolated several organisms from the juice of diseased leaves, and by reinoculation was able to cause infection, but only in a very small number of instances. This he explains by a probable attenuation of the organism when grown on artificial media. Hunger,[4] in a very critical review of the bacterial theory, stated that he was unable in any way to substantiate the findings of Iwanowski, and that although he observed certain bodies in the cells, he was not able to classify them as either bacteria or plasmodia, as they disappeared after heating with phenol chloral hydrate, while the rest of the cell contents were unaffected. More recently Allard[5] has advanced the opinion as a result of his investigations that the disease is parasitic in nature but does not attempt to discuss the character of the parasite, and apparently has made little attempt to demonstrate anatomically the presence or absence of bacteria. Hunger's work is probably the most satisfactory of its kind along this line.

The writer has made examinations of diseased plants, sectioning leaves, stems and even the roots, but has never been able satisfactorily to demonstrate the presence of bacteria in the tissues. In this work a variety of stains were used, chief of which, however, were Ziehl's carbol fuchsin and Heidenhain's iron hæmotoxylin.

It is to be noted in this connection that all investigators have apparently confined their studies to the leaves or part of the plant in which the disease showed itself, and very few attempts, if any, have been made to study the question of the possible presence of bacteria in tissue far removed from the diseased portions. In view of the fact that the juice from all parts of a diseased plant will cause infection, it would be natural to suppose that if bacteria were the causal agent, it should be possible to demonstrate their presence in the different parts of a diseased plant. This has never been done, and in the writer's study of the anatomy of diseased plants it has never been possible to demonstrate the presence of bacteria in the different tissues. The writer has many times attempted to obtain cultures of bacteria from diseased tissue, and in some cases cultures of organisms were obtained on various media, but they proved in every case to be secondary in character, and were not capable of reproducing the disease. In the light of all later investigations the evidence points overwhelmingly to the absence of bacteria, in the present-day sense of the term, as the causal agent of the disease.

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[1] Mayer, A.: Over de in Nederland dikwijk voorkomende Mozaikziekte der Tabak. Land. Tijdschr. (1885).

[2] Prilleux, E. E. and Delacroix, G.: Maladies bacillaires de divers végétaux. Compt. Rend. Acad. Sci. Paris, 118: 668–671 (1894).

[3] Iwanowski, D.: Über die Mosaikkrankheit der Tabakspflanze, Zeit. f. Pflanzenkrank, 13: 1–41, pl. 1–3 (1903).

[4] Hunger, F. W. T.: Untersuchungen und Betrachtungen uber die Mosaikkrankheit der Tabakspflanze. Zeit. f. Pflanzenkrank, 15: 257–311 (1905).

[5] Allard, H. A.: Mosaic Disease of Tobacco. U. S. D. A., Bur. Plant Ind. Bul. No. 40 (1914).

Dissemination Agents.

Insects.

The fact that many fungous and bacterial diseases are often transmitted by insects, as well as other agents, has been long known and thoroughly established, but until Allard (*loc. cit.*) called attention to the fact that the mosaic disease could be carried by aphids, and one in particular (*Macrosiphum tobaci* Perg.), nothing had been published on this phase of the matter. Allard in well-controlled experiments demonstrated beyond a reasonable doubt that the disease was so communicated. Clinton (*loc. cit.*) made a few observations on the infection of healthy plants by the tobacco horn worms which had been feeding on diseased leaves, but was unable to demonstrate that the disease could be so transmitted either by the excreta ejected by the worm or by its biting and feeding on the healthy plants. His results were negative in the few experiments made. Observations made in the field during the progress of the writer's work have not shown conclusively that the disease is communicated by biting insects, such as the tobacco horn worm, grasshoppers and a small black flea beetle of more or less common occurrence in our fields.

Occasionally aphids have been found infesting the leaves of tobacco in our fields, but so far as could be judged were present in too small numbers to be active agents in transmitting the trouble. As a rule, comparatively few aphid infestations are found in our tobacco fields.

In the greenhouse during several winters tobacco plants grown in benches were infested with white fly, and it was at first feared that they might carry the infection from diseased to healthy plants in the same benches. This, however, was not the case, and it has never been possible to demonstrate positively that the white fly is an active agent in the spread of the disease. This insect is, of course, of rare occurrence in our fields, but may possibly do damage in the south. It apparently feeds and breeds freely under greenhouse conditions on the underside of the leaves.

In order to ascertain more definitely the possibility of infection by these insects, adult white flies from badly mosaicked leaves were carefully removed and placed on the underside of the leaves of tobacco plants, enclosed in a small cloth-covered cage, and were allowed to remain on the tobacco leaves of the plants in these cages for four days. After this length of time the plants were removed from the cages and placed on a bench at some distance from those containing mosaicked plants badly infested with white fly. On none of the plants did mosaic develop. The plants were later placed in close juxtaposition to those in the original benches, which, as indicated, were at this time heavily infested with the white fly and badly mosaicked, but although the plants remained until maturity, no cases of mosaic developed on them in spite of a heavy infestation of white fly.

The writer's observations on the activities of aphids as carriers of infection have not been so extensive as in the case of the white fly, as only minor infestations of the former occurred in the greenhouses; and the indications pointed to the fact that, although there were a certain number of aphids present on the leaves of both healthy and diseased plants, so far as was observable no cases of infection from this source arose, as the mosaic developed only on an average of 1 case out of 30, except on the plants which were artificially inoculated with the juice from diseased leaves. It should be stated, however, that aphids present in the greenhouse were not of the same species as that under consideration by Allard, and there is no reason to doubt the accuracy of his observations on the species *tabaci* Perg.

The question of insects as carriers of the mosaic disease as well as of many other diseases is still open to discussion; and it may be that in the case of the mosaic a very heavy infestation of aphids is necessary to bring about a successful infection of healthy plants, as the amount of active infective material carried by such insects would in any case be very small, and accumulative effects of the activities of several insects might be necessary to introduce a sufficient amount of the active principle to transmit the disease.

Workmen.

It has been shown that the disease is highly infectious and it has also been proved repeatedly by many investigators that it is very easy to transmit the disease to healthy plants at the time of transplanting. A workman handling diseased seedlings, and subsequently healthy ones, will very often infect them. Several instances of this have come to the writer's attention, every other plant for some distance in a row developing mosaic within a month after transplanting. The same condition has also been observed by Clinton (*loc. cit.*) in Connecticut, and can only be explained by the fact that the workman's hands were infected through handling a diseased plant, and the infection then transmitted to healthy ones, the causal agent being introduced through broken tissue of the leaves or roots of the seedlings. This method of transmission is particularly striking in the above case, as the same individual plants every other plant in a row when working the ordinary planter. Of course, there have been many cases where every plant for some distance in a row has developed mosaic, but this might be explained if it is assumed that *both* workmen had handled diseased seedlings, or if a number of plants in the lot were diseased. In time, the causal agent becomes so attenuated that infection ceases, and the remainder of the row remains healthy. Experimentally, this method of transmission has also been shown to be possible, and a high percentage of infection has been obtained. In one experiment, after thoroughly rubbing the hands with the tissue of a diseased plant, and then pulling and transplanting healthy seedlings, over 80 per cent. of the transplants became mosaicked within a month. Only a relatively small number of seedlings in this instance were treated in this way, however, the total being 28, of which 24 developed mosaic symptoms within three weeks.

Another manner of transmission is by cultivation. If some of the sap from a diseased plant comes in contact with the tools, etc., employed, there is a possibility that the infection might be carried to healthy plants by this means, but the percentage of infection of this character is probably very low in actual field practice.

The workmen when budding and topping are very often carriers of infection, as they are not as a rule careful to leave untouched the plants showing mosaic symptoms but take the plants as they come, and thus spread the disease to many healthy plants. This method of dissemination has been very often observed, and perhaps is the most fruitful source of infection in the field. The subsequent new growth will almost invariably be mosaic in character, as will also the suckers developing later. The amount of damage to the marketable leaves, however, providing the suckers are removed, is very slight, if any, and cannot be said to injure the leaf in any way, at least in so far as our observations bear on this point. If the suckers are left, however, the plants present a ragged appearance, and the mosaic on the suckers is quite noticeable, and might injure the sale of the crop at the price it ought to command.

Seed.

The causal agent is *not* carried by the seed, and seed from mosaic plants has never produced a larger percentage of mosaicked seedlings than seed collected from healthy plants, when germinated and grown under the same conditions. It is difficult to conceive of this, as it has been shown by Allard (*loc. cit.*) that the tissues closely enveloping the seed in the pod are capable of causing infection; but the writer has saved seed from badly mosaicked plants for three successive years, and the seedlings from such seed showed no signs of the disease, unless infection was produced artificially through some external agency.

It should be pointed out, however, that there is the possibility that the vigor of the seed from mosaicked plants may be less than that from healthy ones, and consequently the plants developed from such seeds, being weaker, might be more susceptible to the factors active in the production of mosaic symptoms. It is impossible to make a definite statement on this point, however, as the writer has not been able to gather sufficient data over a series of years to prove or disprove it.

FERTILIZATION IN RELATION TO MOSAIC DISEASE.

It has been repeatedly shown by many investigators (see historical summary) that a lack of plant food alone will not suffice to produce the mosaic disease, and the writer has also, in connection with the tomato, shown that an *excess* of nitrogen, potash, phosphoric acid and lime will not produce nor intensify the disease.[1]

The same has been found to be true for tobacco. In our experiments on tobacco, the method made use of was to add to each pot the proper amount of a complete tobacco fertilizer (in this case applied at the rate of 3,000 pounds per acre), and then to add an additional amount of nitrogen, potash and phosphoric acid in quickly available forms, equal to that already present. No mosaic was produced in any case, although where the amount of nitrogen was trebled a rather peculiar malformation of the leaves was observed which at first sight might have been mistaken for mosaic symptoms. All inoculations failed to take, however, and the trouble therefore could not have been the true mosaic.

It has been held that liming would lessen the prevalence of the disease, but the writer's observations and experiments do not bear out this statement. Under field conditions this may be the case in certain seasons, but continued observations from year to year on heavily limed areas show no appreciable lessening of the number of mosaicked plants. Seedlings and plants grown in the greenhouse in soil known to be heavily infected indicated the same results, as also did the work on new soil with mosaicked seedlings. Here lime was applied in varying amounts at the rate of from 500 to 6,000 pounds per acre. No appreciable effect on the mosaic disease was observable. The results obtained are given in the following tables: —

TABLE II. — *Effect of Liming on Mosaic.*

[New soil, lime, mosaicked seedlings.]

LIME (POUNDS PER ACRE).	New Soil in Pots (Number planted with Mosaicked Seedlings).	Number of Plants showing Recovery One Month after Planting.
500,	40	-
1,000,	28	-
2,000,	34	-
4,000,	12	-
6,000,	10	-
No lime (check),	5	-

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[1] Twentieth Annual Report, Mass. Agr. Exp. Sta. (1908), p. 140.

The lime was applied to this new soil, in the different amounts indicated, one week previous to the setting of the plants.

No appreciable differences were observable in the subsequent growth as regards intensity of mosaic symptoms, all the plants being comparatively evenly mosaicked. There was not a single case of recovery.

TABLE III. — *Effect of Liming on Mosaic.*

[Infected seed bed soil, lime, seed.]

LIME (POUNDS PER ACRE).	Per Cent Infection (Seedlings Twelve Weeks Old).
500,	12.0
1,000,	18.4
2,000,	9.8
4,000,	21.0
6,000,	8.6
No lime (check),	13.7

The lime was here applied to a soil which was heavily infected, and the seed sowed very thinly in the flats containing the various amounts of lime and soil. The seedlings were allowed to grow in the flats until they were counted. They were naturally crowded somewhat, but were free from insects during the period of growth. It is possible that some infection may have occurred, however, but there are very strong indications that liming had no beneficial action in lessening the disease. As the results are so variable the matter cannot be considered as absolutely settled, but certainly no consistently favorable results were obtained in this experiment from the use of lime.

EFFECT OF COLORED LIGHT ON MOSAIC DISEASE.

In connection with work on the mosaic disease of tobacco it had long been noted, in that section of the Connecticut Valley where the crop was grown under shade, that the plants appeared in general to be much less affected with the mosaic disease than were those grown in the open. This fact has already been noted by Sturgis[1] in Connecticut. Investigations were outlined, in conjunction with other work on this disease already under way, relative to a study of the effects of various light conditions on the intensification or reduction of the disease. While the writer's preliminary work was in progress, Lodewijks[2] published a paper on the effects of colored light on mosaic-diseased plants, and as a result of his experiments stated that a cure was effected by blue light, red light diminished the disease, and suffused light checked it somewhat. In brief, his methods of experimentation and conclusion were as follows: —

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[1] Sturgis, W. C.: On the Effects, on Tobacco, of Shading and the Application of Lime. Conn. Agr. Exp. Sta. Ann. Rept., 23, 252–261 (1899).

[2] Lodewijks, J. A., Jr.: Zur Mosaikkrankheit des Tabaks. Rec. Trav. Neerlandais, Vol. 7, 107–129 (1910).

The diseased leaves of a plant were covered with a cloth hood of the desired color, of a sufficient size to allow ample room for growth. The apparently healthy basal leaves were left uncovered and exposed to the normal daylight. After a time the hoods were removed, and it was found that in the case of the plants exposed under the blue hood a cure was effected; those exposed under a red hood showed a diminution in the severity of the disease; and in the case of plants exposed to the suffused light alone the disease was somewhat checked. The cloth used for the red and blue hoods was a rather coarse cotton material similar to that used for making flags.

Several investigators had noted the apparent beneficial effects resulting from growing diseased plants in suffused light, but Lodewijks was the first to really study the effects produced by colored light, although Bauer appears to have made some observations on this point. As in no case could the writer find that Lodewijks in his work had reinoculated from the apparently cured plants to healthy ones, to prove the presence or absence of the causal agent, and as it is often present and active in apparently healthy leaves of diseased plants, as has been shown many times, it was thought necessary to settle the point as to the presence or absence of the causal agent in plants treated as in Lodewijks' work.

Method. — The method of treatment of diseased plants was in every way similar to that employed by Lodewijks as to texture of cloth, methods of covering the plants, etc. The cloth covers were held away from the plant by means of wire hoops, and the cloth was tied around the stem of the plant below the diseased leaves. Plate V. shows a hood in place over a field-grown plant, and gives a clear idea of the arrangement of the hoops, etc.

The cloth used was a coarse grade of cotton, and the colors were cadmium orange, ox-blood red and indulin blue.[1]

Plants showing well-developed symptoms of the mosaic disease were selected for the experiment, none of which had less than four characteristically diseased leaves, the lower remaining leaves apparently healthy. The hoods were placed over the diseased leaves as above noted, and left on for the required time, in most of the experiments twenty to thirty days. At the end of this period the hoods were removed and the plants carefully examined for *visible* symptoms of the disease. Two leaves from the upper (*i.e.*, the part under the hood) portion of the plant were removed under absolutely aseptic conditions, the juice expressed and healthy plants inoculated therewith by means of glass capillaries inserted just below the terminal leaflets. Control inoculations with distilled water and boiled juice were also made at the same time. The plants, after the

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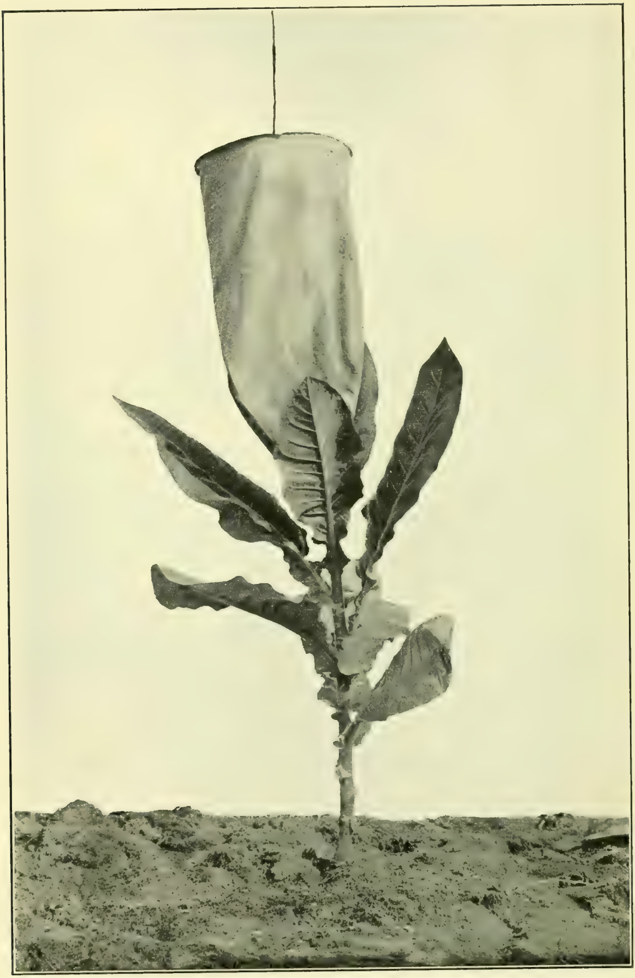
[1] Ridgway, Robert: Color Standards and Color Nomenclature. Washington, D. C. (1912).

PLATE V.



Effect of colored light on mosaic disease; showing method of attaching hoods over leaves.

removal of the leaves above mentioned, were allowed to grow to maturity under normal light conditions.

Most of the experiments were carried on in the greenhouse, where temperature and other conditions were under more direct control than in the field, although field experiments later repeated gave the same results, but, of course, in this case there was a greater chance of subsequent infection through careless handling, insect attacks, etc. In the following paragraphs are tabulated the results of a typical series of experiments relative to the effects of light on mosaicked plants.

Experimental Data.

Red Cloth. — Three plants were covered with the red cloth hoods for twenty days. The covers were then removed, and in all cases visible symptoms of the disease were still present, although the color variation between light and dark green areas was not so marked as at the beginning of the experiment. All the new growth, in addition to the leaves diseased at the time the hoods were put on, also showed the mottling distinctly. A week after the hoods were removed all the plants still showed the disease in undiminished severity.

Healthy plants inoculated with the juice from the leaves confined under the hood became diseased in from nine to eighteen days' time. Controls inoculated in the same manner with boiled juice from the same leaves, and with distilled sterile water, remained with very few exceptions healthy. Table IV. gives the results of the inoculation experiments in one series.

TABLE IV. — *Result of Inoculation with Juice from Plants grown under Red Hoods.*

PLANT NO.	Number of Healthy Plants Inoculated with Juice from Leaves of Treated Plant.	Number of Inoculated Plants showing Mosaic at the End of Eighteen Days.
A-1, ...	6	6
B-1, ...	7	[illegible]
C-1, ...	4	4

Controls inoculated with boiled juice, 10; diseased in eighteen days, 1.
Controls inoculated with distilled, sterile water, 10; diseased in eighteen days, 0.

From the above results it may be seen that there was a diminution in the color variation in diseased leaves; it was not of a permanent character, the plants all showing the disease in undiminished severity again after a short exposure to normal daylight. The causal agent of the disease was still highly infectious.

In a second series the hoods were allowed to remain over the plants for thirty days, as it was thought that a twenty-day exposure might have been too short, but no appreciable variation in the results was obtained as a result of the longer treatment.

Orange Cloth. — In this series two plants were covered with orange hoods for a period of thirty days. On removing the covers it was found that the visible symptoms of the disease were, if anything, intensified. The growth was somewhat more spindling, the leaves narrower, and the light and dark green areas very clearly defined. Infection was produced from both plants by inoculation into healthy plants. The causal agent was very active and highly infectious.

Blue Cloth. — The diseased parts of three plants were covered with blue cloth hoods, as in the preceding experiments, for a period of twenty-five days. The covers were then removed and a careful examination of the leaves made. On plants A-2 and B-2 no visible symptoms of the mosaic disease could be observed, although a slight tendency towards curling was noticeable on a few of the leaves. The leaves were all uniformly light green in color, and aside from this, appeared normal. Plant C-2, however, showed on two leaves a slight mottling. Two weeks after the hoods were removed, plants A-2 and B-2 did not show any marked symptoms of the mosaic disease other than a faint mottling of a few leaves, not sufficient, however, to seriously injure the leaf. Plant C-2 developed mosaic again in the same length of time, but not as seriously as before the treatment. It may be that the mottling on A-2 and B-2 was due to the maturing of the plant, although this mottling is usually distinctive enough to be readily differentiated from that caused by the mosaic disease.

Healthy plants inoculated with the juice of leaves from plants A-2, B-2 and C-2 contracted the disease almost without exception. Controls inoculated with boiled juice failed to develop the disease. Table V gives the results of the inoculations.

TABLE V. — *Results of Inoculations with Juice from Plants grown under Blue Hoods.*

PLANT NO.	Number of Healthy Plants Inoculated with Juice from Leaves of Treated Plant.	Number of Inoculated Plants showing Mosaic at End of Eighteen Days.
A-2, ...	8	5
B-2, ...	4	4
C-2, ...	10	9

Controls inoculated with boiled juice, 6; diseased in eighteen days, 0.
Controls inoculated with sterile distilled water, 6; diseased in eighteen days, 1.

The above results show that when blue light is used there is a suppression of leaf color variation more or less permanent in character, the treated plants, with one exception, showing no typical symptoms of the disease for at least two weeks subsequent to the removal of the hoods. It cannot be said, however, that the disease was controlled, as inoculation of healthy plants with the juice from these leaves produced the disease in nearly every case.

The causal agent of the disease was still very active in the *apparently normal fully recovered leaves*, and was highly infectious.

Discussion of Results. — The results of these experiments do not agree entirely with those obtained by Lodewijks, particularly in the case of action of the blue light, inasmuch as the plants covered with the blue hoods, although showing an *apparent* recovery from the mosaic, still contained the causal agent of the disease, and by inoculation with the juice expressed from these plants into healthy plants the disease was again produced in practically all cases. It should be noted that the visible symptoms of the disease were suppressed, the reason for which may be as Allard (*loc. cit.*) suggests in his work on the mosaic disease of tobacco. He states, with respect to Lodewijks' observations, "If the malady in question was true infectious mosaic disease, one is inclined to believe that covering the young plants temporarily reduced the color contrasts of the mottled areas. These changes may have led Lodewijks to conclude that a partial or a complete cure had been effected in his experiments."

It might be inferred from the above that on the removal of the hoods exposing the plants to normal daylight, they would soon regain the color contrast, but this is not entirely so in the case of the blue light, as has been shown. The apparent recovery, therefore, is not entirely the result of a suppression of color contrast due to the action of blue light on the leaves as suggested by Allard, but is undoubtedly so in part.

It is evident that the treatment of plants as above recorded does not destroy the causal agent of the mosaic disease, whatever may be its character, the treated leaves apparently still containing the causal agent, very probably in the same manner as do the parts of a plant which do not show visible symptoms of the disease, as the stem, lower leaves, roots, etc., the juice of which is often highly infectious. It would appear from the results that the new terminal growth subsequent to the removal of the hoods would develop the trouble, and this was the case in plant C-2, but not apparently so with plants A-2 and B-2. Lodewijks' opinion, therefore, that in the plant a "virus" and "anti-virus" are present, and that certain abnormal conditions cause the "virus" to be produced in excess, bringing about a mosaicked appearance, while if the "anti-virus" is produced in excess, immunity is secured, will hardly hold, as it is clearly shown that even after apparent cure the causal agent is present and active.

It is significant to note that under the influence of blue light both assimilation and starch formation are decreased, thus bringing about a partial starvation, as it were, not, however, serious enough to reduce greatly the total starch formation and assimilation of the whole plant; while at the same time the chlorophyll production is very little changed if a comparison of the color of the normal and treated leaves can be taken as a basis of such a comparison. This latter fact has already been noted by Lodewijks in his work on the disease.

It is, therefore, indicated by the results obtained in the preceding experiments that the different colors have little or no effect on the causal agent of the disease, but in the case of the blue there is a strong depression of the macroscopic symptoms of the disease.

Biochemical Studies.

Enzyme Activities in Healthy and Diseased Plants.

The study of enzymes in relation to diseases, particularly those of a so-called physiological nature has not been extensively gone into as yet by investigators, but it is believed that a study of their activities and reactions should be made, not only in the case of physiological troubles, but also those caused by fungi and bacteria, as it is the writer's firm belief that the activities of a large number of the fungi, and their effects on the respective hosts, are in a great measure due to the action of either exoenzymes or endoenzymes produced by the fungi concerned. There is a possibility that the future may show a great advance in the study of host resistance, etc., when the conditions under which enzyme activity in fungi and bacteria takes place are better known, and plants may possibly be bred to a condition of producing either a sap in which these activities cannot take place, or will produce anti-enzymes which will inhibit the activities of the enzymes contained in the respective fungi.

Although many have made a study of this disease, very few have concerned themselves with the question of the enzyme activities; among the first to make mention of this phase of the question was Woods (*loc. cit.*), who found that the enzymes designated as peroxidases were at least diffusable, and occurred apparently in larger amount in diseased leaves than in healthy ones; also that their action was twice as strong in the light green areas as in the darker portions of the leaf. Koning (*loc. cit.*), as a result of his investigations, came to the conclusion that the disease was caused by a certain enzyme, which he stated to be oxidase, and the action of which he described. He believed that it was formed in the plant under certain conditions. Heintzel[1] also found oxidizing enzymes present which were more active, if not present in greater amounts, in diseased plants than in the normal plants. Woods later (1902), in his work on the mosaic disease, verified his former observation, and stated further that the diastase activity was much inhibited in the case of diseased plants. He attributed the lessened diastase activity to the presence of excessive amounts of oxidizing enzymes, and showed experimentally that diastatic action is inhibited by the presence of oxidizing enzymes. This is the only work that has been accomplished up to the present time, so far as relates to a study of the enzyme activities involved in this disease. Only two enzymes have been considered, namely, the oxidase and diastase, and it should be stated that in the light of later developments in the determination and estimation of enzyme preparations and activities the results obtained in some cases might well be open to some criticism.

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[1] Heintzel, K.: Contagiose Pflanzenkrankheiten ohne Microben mit besonderer Berücksichtigung der Mosaikkrankheit der Tabaksblätter. Erlangen, 46 p., 1 pl. (Inaugural Dissertation) (1900).

Loew,[1] while working with tobacco, discovered the presence of an enzyme which he called catalase, but he made no observations relative to its activities in the case of mosaic-diseased plants. The results of the writer's studies on enzyme activities of healthy and mosaic plants are detailed below.

Method. — In the experiments here detailed the enzymes under discussion were studied, in so far as was possible, (1) with regard to their presence or absence in (*a*) leaves, (*b*) stems and (*c*) roots of healthy and diseased plants (this was considered necessary, as it has been found that, irrespective of the parts showing visible symptoms of the disease, the sap from all other parts also is capable of transmitting the trouble); (2) with regard to the age of the plant; (3) with regard to the growth of the plant under different conditions. These will be discussed in detail under their respective sections.

The methods employed for the estimation were for the most part those which by experience have been found satisfactory, and in the main give quantitative results; in some cases the results are more or less qualitative in nature, owing to our present insufficient knowledge of the methods of isolation and action of the enzyme involved.

It should be stated that plants used in the experiments were both field and greenhouse grown, but no essential differences in results were obtained from the two series. The individual experiments will not be given in detail, but as the determinations of any given series were made in every case in the same manner, only average results with the maximum and minimum readings will be given. The experiments are, however, described in sufficient detail to enable those interested to follow the methods employed closely enough to check up the work of the writer.

Catalase (*leaves*). — A comparison was made of the catalase activity of healthy and diseased leaves, as it had been noted as early as 1908 by the writer that there was apparently a great difference between the catalase activity of healthy and mosaic-diseased tomato leaves, and later the same was found to be true in the case of tobacco. At that time only rough determinations were made, but since then the writer has made hundreds of determinations, the results of which have borne out the observations made then, and indisputably established the fact that there is a wide difference in the catalase activity of healthy and diseased leaves.

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[1] Loew, O.: Catalase: A New Enzyme of General Occurrence, with Special Reference to the Tobacco Plant. U. S. D. A., Bur. Plant Ind., Bul. No. 68 (1901).

In all the experiments freshly collected material was used, and the determinations made almost immediately after collection. The usual procedure was as follows: —

A weighed amount of leaf was ground thoroughly with a weighed amount of acid-washed sand and a certain volume of double distilled water, and the whole washed into the apparatus with sufficient double distilled water to bring the volume up to the standard volume used in the particular series in question. This, of course, gave to each flask a standard constant dilution value. To this mixture was then added a like volume of 1 per cent. solution of Merck's perhydrol, thus making the H_2O_2 concentration of the total mixture .5 per cent. The amount of oxygen liberated in ten minutes was arbitrarily taken as the measure of enzyme activity. Several different forms of apparatus were used, but for large amounts of leaf any ordinary water displacement method was found to be very satisfactory. (Care should be exercised where this mode of analysis is used, to take into account the absorption of oxygen by the water.) In making determinations where the amount of material was very small, the apparatus designed by Lohnis for use in milk examinations was found to be more convenient. Practically all determinations were made at temperatures ranging from 17° to 23° C. The action of the catalase is much accelerated by shaking, as pointed out by Loew, and each test was shaken under exactly similar conditions in all the determinations made. It was found necessary to use this method for the determination of the catalase activity, as any method involving titration, such as the permanganate method, was unsatisfactory, due to the reaction of certain constituents in the tissue with the reagents.

Table VI. shows the relative amounts of oxygen developed in normal tobacco leaves, and it is to be noted that the catalase of the dark green leaves was much more active than that of the light green leaves. This was found to hold true, to a certain extent, for light and dark green leaves even on the same plant. The basal leaves of older plants, which in some cases were almost mature, and of a lighter color than the middle and upper leaves, developed in every case relatively less oxygen. This was particularly true in the case of Havana tobacco. Broadleaf did not show such a wide divergence, but it should also be stated that in the Broadleaf plants employed in the determinations the basal leaves did not show any great color difference.

As will be noted, some of these experiments were made with plants grown under field conditions, but a greater number were made with plants grown in the greenhouse, under control conditions.

TABLE VI. — *Catalase Activity in Healthy Leaves.*

Weight leaf used=3 grams. Time of action=10 minutes. Temperature=17 to 23° C. Vol. of leaf+H_2O=100 c. c. Vol. 1 per cent. H_2O_2 added=100 c. c. g=greenhouse. f=field.]

Series.	VARIETY.	AMOUNT OF OXYGEN DEVELOPED (CUBIC CENTIMETERS).			Color of Leaf.	Number of Determinations.	Age of Plant.
		Maximum.	Minimum.	Average.			
A	Havana (g),	139.0	97.0	119.8	Dark,	40	Half grown.
B	Havana (g),	103.0	48.0	56.0	Light (basal),	26	Nearly mature.
C	Havana (g),	94.0	61.5	77.5	Light (whole plant light),	7	Half grown.
D	Broadleaf (g),	126.4	101.0	113.7	Dark,	3	Half grown.
E	Broadleaf (g),	154.0	119.5	126.3	Dark,	11	Nearly mature.
F	Broadleaf (g),	106.7	78.2	93.4	Light (basal leaves),	5	Nearly mature.
G	Havana (f),	176.0	115.5	124.8	Dark,	19	Half grown.
H	Havana (f),	147.6	93.1	100.2	Dark,	14	Nearly mature.
I	Havana (f),	121.0	72.9	91.0	Light,	6	Half grown.

These results show that the catalase activity varies somewhat even in healthy plants, dependent upon age and also, apparently, on the general condition of the plant. It shows clearly, also, that in plants of approximately the same age the catalase activity varies somewhat between plants with dark green leaves and those with light green leaves.

Even on the same plant this holds true, as can be seen from the results tabulated below.

TABLE VII. — *Catalase Activity of Light and Dark Leaves from Same Plant.*

[Plants nearly mature; procedure as in Table VI.]

PLANT NO.	Number of Determinations.	Light Leaves, Cubic Centimeters of Oxygen developed (Average).	Dark Leaves, Cubic Centimeters of Oxygen developed (Average).
B_1,	4	51.8	119.8
X_{11},	3	62.0	125.5
104,	3	71.4	93.7
A_{17},	6	58.1	79.3

An examination and determination of the catalase activity in diseased leaves shows that the amount of oxygen developed is relatively much less than in the case of healthy leaves. In the table below are given some of the results obtained from diseased leaves. In these experiments the leaf tissue was used without reference to the light and dark areas of the individual leaf. It is significant that the activity is very much less than in healthy leaves. All the plants used in this series were badly diseased. It should be stated that in apparently mild cases of the disease the variation from the normal catalase content was not so great. The results shown here can hardly be compared with those given in Table VII., as the plants were not in some cases of the same age, nor were they grown at the same time.

TABLE VIII. — *Catalase Activity in Diseased Leaves.*

[Plants badly diseased; procedure as in Table VI.]

PLANT NO.	Number of Determinations.	Cubic Centimeters of Oxygen developed (Average).
P_6,	8	47.2
R,	6	32.8
3_a,	9	54.5
A_x,	11	69.6
Total,	34	51.0

In the next table will be found a comparison of the results of catalase activity in healthy and diseased leaves from plants grown at the same time and under identical conditions. The plants were inoculated artificially in as uniform a manner as possible.

TABLE IX. — *Catalase Activity in Leaves of Healthy and Diseased Plants of Same Age.*

[Procedure as in Table VI.]

LEAVES.	Number of Determinations.	Cubic Centimeters of Oxygen developed (Average).
Diseased,	10	52.3
Healthy,	10	119.0

The values here obtained simply substantiate those given in preceding tables, but in addition allow of a direct comparison.

The leaf tissue was used in the preceding experiments without regard to the light and dark green patches on the individual leaf.

It was thought that an examination of the light and dark green areas of individual leaves of mosaicked plants might give a clue as to whether the activities of the catalase were inhibited in one or both of these areas in comparison with a leaf from a healthy plant of approximately the same age and color.

It was found that the catalase activity of the dark green areas approached that of the normal leaf of the same color, while the catalase activity of the light green areas was much below normal, even in the case of a light green normal leaf being used for comparison. The values obtained are given in Table X.

TABLE X. — *Catalase Activity in Diseased Leaves.*

[Comparison of light and dark green areas; procedure as in Table VI.]

SERIES.	Number of Determinations.	CUBIC CENTIMETERS OF OXYGEN DEVELOPED (AVERAGE).	
		Light.	Dark.
X,	4	42.1	73.6
0,	3	37.0	95.4
21,	8	54.3	103.0

Diastase. — It is a well-known fact that diastase is intimately connected with metabolism in the leaf in practically all chlorophyll-bearing plants, as well as in many of the fungi, and the relations of the activities of diastase in the mosaic disease are of rather significant import, as can be easily shown. It was pointed out several years ago by Woods (*loc. cit.*) that the action of oxidizing enzymes when present in solutions containing diastase tended greatly, under ordinary conditions, to inhibit the activities of the diastase. Turning more particularly to the mosaic disease, he made the observation that in the cells of the light green areas, although they formed starch practically in a normal manner, so far as could be observed the starch was not translocated, and that in the morning there was practically as much starch present as at night, which is not the case in a normally functioning leaf. In this case it was found that practically all the starch disappeared in the night and was translocated.

Recently there has been more or less contention as to the exact method of action of diastase on starch, and within the last two or three years important investigations have resulted in the opinion, substantiated more or less in detail, that the diastase of the older writers is not one enzyme alone, but is made up of at least two components. The first of these breaks down the starches into, or as far as, the erythro-dextrine and achro-dextrine stage, the second component taking up the action from this point and completely hydrolizing the starch to the sugar compounds which are found to be present, as the next step in the process of metabolism.

It was in the light of these investigations that the writer took up the question of the diastase activity in the mosaic disease, and it was found to be less active in the leaves which showed severe symptoms of the disease than in those which showed only a slight trace. There was, however, apparently a greater or less breaking down of the starch in all the leaves examined, so far as could be determined by the colorimetric methods, which, although not altogether satisfactory, may be relied upon as much as any of the present-known methods of determination. At the morning examinations the starch did not in some cases take on the color of the normal starch in the healthy leaves, but was accompanied by a yellow brown to a reddish or violet coloration, dependent somewhat on the strength of the indicator used. The strength of the iodine solution used in this case was a fiftieth normal iodine-potassium iodide solution. This reaction would indicate that the starch to a certain extent had been acted upon at least partially by the diastatic enzymes, and would indicate also that it was possibly the first of the components above mentioned which was more active, and that the second was more or less inhibited in its action. In the normal leaf, of course, there was a certain amount of starch present indicated by the blue coloration of the granules. The amount was slight, however, compared to that in the diseased leaves, and in no case was there any of the brown or violet color, almost complete hydrolysis having apparently taken place very rapidly. This would indicate, as pointed out by Woods, that the oxidizing enzymes, of which we will make mention, and which are present in excessively large amounts in the diseased areas of the leaf, do play an important rôle in the controlling or inhibiting of the activities of the diastatic enzymes, but not on the diastase in the old conception of the term. Rather it might be said the action is on the primary enzyme concerned in diastatic activity, if the newer concept of diastatic activity above advanced is true, as it would seem to be from the unpublished investigations of Roessler of the University of Prague, who was able to separate by salting out from a very carefully prepared solution of the ordinary diastase at least two components having the respective actions above mentioned. In no case, as indicated by the color reaction obtained, did we get a complete hydrolysis of a large amount of starch, the process only being carried on, apparently, as has been indicated, — as far as the erythro-dextrine and achro-dextrine stage. It was attempted in our experiments to isolate or rather separate out diastase in a more or less pure form from the leaves of healthy and diseased plants, and although certain results were obtained, it was rather a difficult matter, as in the writer's experience it has been found that diastase is one of the most difficult of the enzymes to purify to any extent. The protective colloids, etc., during the purification are separated away from the enzyme aggregate, and the purer ferment becomes less active. The reason for this cannot be very well explained at the present, but it is the experience of all investigators with diastase that this is a fact. However, results were obtained which seemed to indicate that the diseased leaves contain relatively less "diastase" than do the normal healthy leaves.

Chlorophyllase. — This enzyme has been found to be always present with chlorophyll in amounts directly proportional to the amount of chlorophyll present, and according to Willstätter and Stoll[1] does not bring about an hydrolysis but an "alcoholysis,"

$$RCOOC_{20}H_{39} — C_2H_5OH \;.\; RCOOC_2H_5 — C_{20}H_{39}OH$$

in the presence of ethyl alcohol. It forms the alcohol phytol, $C_{20}H_{39}OH$, from the radical in the presence of ethyl alcohol and not water only.

Very little is known about its action in the plant cell, and although the writer was able to demonstrate its presence in both healthy and diseased leaves, no quantitative data were secured as to its relative activity in healthy and diseased tissue. Until better methods are worked out for its purification and rapid determination it would be futile to hazard an opinion in regard to its specific action in the cells of healthy and diseased leaves.

Oxidases and Peroxidases. — Woods (*loc. cit.*) was one of the first to observe that in mosaic-diseased leaves the oxidase activity was greatly increased. Since then it has been found that in the curly dwarf disease of the potato and sugar beet the oxidase activity is greatly increased in the diseased leaves as compared with that of the normal. These two diseases have been for the most part regarded as physiological, and it is a significant fact that this excessive activity of oxidizing enzymes has been more frequently noted in diseases of this character than in those which are caused by bacteria or fungi. The reaction of the host is apparently different in the latter case.

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[1] Willstätter and Stoll: Unt. über Chlorophyll XI und XIII. Über Chlorophyllasa. Liebig's Ann. der Chemie., 378, 18 (1910); 380, 148 (1911).

Bunzel[1] has noted that the oxidase activity varies with the age of the plant in the curly dwarf disease of potato, reaching its greatest activity when the plant growth ceases.

The writer has also found this to be true for tobacco to a certain extent, and always met with greater activities of the oxidases as the leaves were approaching maturity. This was marked in the case of normal plants, but not so much in the case of diseased leaves.

In the writer's examinations of healthy and diseased tissue not only qualitative colorimetric methods were employed, but also a simplified Bunzel's oxidase apparatus was made use of. This has been found to be the most satisfactory method for the quantitative estimation of oxidase activity.[2]

A few of the quantitative results obtained are given in Table XI.

TABLE XI. — *Oxidase Activity in Normal and Mosaic Sap.*

[Manometer readings in centimeters of mercury. Bunzel apparatus mod.]

EXPERIMENT.	Time in Minutes.	Normal.	Diseased.
A,	0	0	0
	30	—0.60	—0.80
	60	—1.09	—1.23
	75	—1.12	—1.29
	120	—1.22	—1.43
B,	0	0	0
	30	—0.32	—0.50
	60	—0.80	—0.70
	75	—1.02	—0.96
	120	—0.92	—1.21
C,	0	0	0
	30	—0.51	—0.46
	75	—0.63	—0.88
	100	—0.70	—0.91

It will be noticed that the mosaic sap is higher in total and average in every instance.

For the qualitative determinations the usual guaiac test was employed. The guaiac test for oxidases and peroxidases is too well known to require an extended explanation. The results obtained by this method in every case showed the diseased leaves to contain much more oxidases than the healthy ones of the same age; this was also true for peroxidases, but here, of course, the reaction with guaiac was somewhat masked owing to the presence of the oxidases and their reaction.

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[1] Bunzel, H. H.: Oxidases in Healthy and Curly Dwarf Potatoes. Jour. Agr. Research, Vol. II., 5, 373-404 (1914).

[2] Bunzel, H. H.: The Measurement of the Oxidase Content of Plant Juices. U. S. D. A., Bur. Plant Ind., Bul. No. 238 (1912).

In examinations of the roots of healthy and diseased plants the same condition was observable; there was always an excessive activity of the oxidizing enzyme to be noted.

In going over the results of the experiments with the enzymes in question, the main point brought to the attention is that there is in all diseased plants an excessive activity of the oxidizing enzymes, and a corresponding decrease in the activity of the diastatic enzymes and catalase. This at least indicates a very much disturbed equilibrium and a consequent derangement of normal function on the part of the cells. Naturally the ones most affected by this disturbance are the dividing or meristematic cells, as these are the cells upon which the plant is dependent for its subsequent growth, and any deviation from the normal is more likely to be indicated in the development of these cells than in those of the other parts of the plant. Any change in function induced here will leave its imprint to a greater or less extent on the cell during its subsequent existence, hence the peculiar manifestations of the disease in the leaves.

It is true that plants attacked by parasites sometimes show an excessive activity on the part of certain enzymes, but, as a rule, the disturbance is more local in its nature. It is also a fact that malnutrition, such as partial starvation, drought, etc., will bring about an excessive production or activity of the oxidizing enzymes in particular, as has been pointed out by Bunzel, of general distribution throughout the plant; but this, except in cases of maturing plants, changes upon restoration of normal conditions, and tends to become normal.

Reaction of Mosaic Sap with Various Substances.

We have seen that the enzymatic activities of the plant are very much disturbed in disease; also that it has been impossible to demonstrate the presence of any forms of bacteria or fungi either in the tissues themselves or in the expressed juice.

It is a fact, as shown by practically all investigations, that the disease is very infectious. This fact alone in the minds of many is sufficient to place the causative agent among the parasitic organisms. The field, however, is limited to that class of organisms designated as "ultramicroscopic" organisms, about which very little is known, and in the case of plant diseases not even a semblance of the demonstration of the activities of such organisms has been made.

Owing to the fact that the enzyme activities are much changed, as has been demonstrated in the preceding pages, and also to the fact that not only the activities of the oxidizing enzymes are changed, but also the activities of others; it was believed by the writer, with Woods and others, that the disease might be physiological in nature, particularly in so far as the causal agent, not being a living organism in the ordinary conception of the word, was concerned.

So little is known about the action of the so-called ultramicroscopic organisms that it is an open question in the writer's mind whether this division should be the dumping ground for all infectious diseases about the etiology of which little or nothing is known.

It is conceivable that other causes, not organic in nature, may be able to produce the manifestations of parasitism. Under this type of infection would be included infectious diseases caused by enzymes or the resultant product of the activities of a group of enzymes.

Certain reactions of the juice from diseased plants tend to confirm this view, and in the following pages are given the results obtained by the writer and other investigators relating to the reactions of these juices with various reagents.

Drying. — It has been shown by various investigators that the dried leaves of the mosaic-diseased plants retain their infectious qualities for a long time. Beijerinck and Allard found that diseased leaves were capable of causing infection after being dried for periods of two years and eighteen months, respectively. The writer has used material three years old, and obtained infection in a great majority of cases. The results obtained are given below.

TABLE XII. — *Air-dried Mosaic Leaves, finely ground and macerated with Cold, Distilled Water.*

[Leaves (herbarium specimens) three years old.]

Number of Plants inoculated.	POINT OF INOCULATION.	Number of Plants infected.	Per Cent. Infection.
10	Below terminal leaflets, ...	10	100
12	Main stem near base, ...	11	91
7	Midribs of a basal leaf, ...	6	86
13	Midribs of a basal leaf, ...	12	90

Filtration. — The use of various filters such as the Chamberland, Berkefeld and Kitasato types, as a means for the separation of bacteria and other organisms in a fluid, has been widely adopted in recent years, and more recently filters possessing different sized pores have been used for differential diagnostic purposes in work on the so-called "ultramicroscopic" organisms, enzymes and toxins. While these methods are without doubt of importance, it should always be borne in mind that to obtain true filtration effects comparatively large volumes of the fluid should be used, otherwise there is a strong possibility, particularly in the case of enzymes, that instead of a filtration occurring at once, a large amount of certain constituents may be adsorbed (dependent on the nature of the filter), and that true filtration may not take place until comparatively large amounts have been drawn through the filter. The writer has noted this particularly in work with enzymes, many of which are strongly adsorbed by various substances. Aside from the "ultramicroscopic" organisms, however, the bacteria cannot pass through many of these filters.

With reference to the causal agent in mosaic sap it has been found that it passes through both the Chamberland and Berkefeld filters, and even the finer grade of Berkefeld filter allows the passage of the causal agent. Beijerinck (*loc. cit.*) showed that the juice was still infectious after being passed through the Chamberland filter, and Allard (*loc. cit.*) and Clinton (*loc. cit.*) have both shown that the juice was infectious after passage through the Berkefeld (normal) filter. The results obtained by the writer agree with these observations, and also the juice was found to be infectious after passing it through the fine Berkefeld candle. The Kitasato filter was also used, and here positive infection was also obtained, although the percentage was small. The writer attempted to repeat these experiments with the Kitasato filter during the past year, but was unable to obtain the filter. In all cases relatively large amounts of the sap were used after filtration through paper.

The average percentage of infection obtained with each filter in the writer's experiments was as follows: —

	Per Cent.
Chamberland (average of 3 examinations, 1911),	91.0
Berkefeld (normal; average of 5 examinations, 1911),	63.0
Berkefeld (fine; one test only, 1914),	47.0
Kitasato (average of 2 examinations, not dated),	40.5

The work with the fine grade of Berkefeld and Kitasato filters should be repeated, but there are sufficient indications to warrant the insertion of these results at this time.

Resistance to Antiseptics. — The writer has at various times treated filtered and unfiltered juice with many of the antiseptics such as are commonly used to prevent bacterial action.

The following table contains the data and results obtained in one typical series of experiments of this character: —

TABLE XIII.

ANTISEPTIC.	Amount of Sap used (Cubic Centimeters).	Period of Treatment.	Infection.
Toluol (2 c. c.),	10	2 months.	++
Toluol (2 c. c.),	10	4 months.	++
Chloroform (saturated at beginning),	10	2 months.	++
Chloroform (in excess),	10	2 months.	—
Chloroform (saturated at beginning),	10	4 months.	+
Chloroform (in excess),	10	3 days.	—+
Thymol (2 per cent.),	10	2 months.	+
Thymol (2 per cent.),	10	4 months.	+
Ether (saturated),	10	2 months.	+
Ether (saturated),	10	4 months.	+
Formaldehyde (1–4 H_2O, 1 c. c. added),	10	2 months.	—
Formaldehyde (1–4 H_2O, 1 c. c. added),	10	10 days.	—
Carbolic acid (5 per cent., 10 c. c. added),	10	2 days.	—
Chloralhydrate (½ mol.),	10	2 days.	—
Chloralhydrate (½ mol.),	10	20 hours.	—

++ = very infectious.
+ = infectious (over 40 per cent.).
—+ = one or two cases of infection, possibly accidental.
— = no infection.

From the preceding table it may be seen that the sap containing the causal agent of the disease varies greatly in its reaction to so-called antiseptics and other compounds. The writer[1] has already pointed out in a previous publication that the influence of certain capillary active substances on enzymes is very variable, aside from the specific toxic qualities of certain of these substances. In comparing the reaction of the sap containing the causal agent to certain of these compounds we find that there is a similarity of reaction to that shown by the enzymes. In the paper above cited it was shown that those compounds which changed the surface tension had, as a rule, dependent on their physical properties (hydrocolloidal or lipocolloidal), a certain definite effect on enzyme activities.

Taking up the discussion of the results in detail we find in toluol a compound which is not soluble in water to any great extent, and hence, behaving like a lipocolloid, having no effect on the action of the causal agent contained in the sap. Toluol, as a rule, has a more or less definite inhibitory action on living organisms.

Chloroform, when present in the sap not to exceed saturation, behaves also like a lipocolloid, as it is only very slightly soluble in the water, and we find in this case that the activity of the agent is not destroyed. Chloroform in excess, however, does destroy apparently the causal agent of the disease. It is noteworthy that this action of chloroform exactly parallels that found to be the case with enzymes.

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[1] Chapman, George H.: The influence of Certain Capillary-Active Substances on Enzyme Activity. Internat. Zeitschrift für Physik.-chem. Biologie., I Band, 5 u. 6 Heft (1914).

Thymol, when used in 2 per cent. concentration is very often used as a preventive to bacterial action, and also prevents the growth of fungi. We find, however, that when it is present in concentration not exceeding 2 per cent. in the sap the causal agent still possesses its infectious qualities for some time.

Ether is a substance which, like chloroform, has lipoid-like properties, but which has a definite action on the surface tension, lowering it considerably. Sap containing ether to the saturation point, which lowers the surface tension from 1 to about .619, was still infectious four months after treatment, although the percentage of infection was much decreased.

A solution of the sap containing approximately .8 per cent. of actual formaldehyde was very injurious, and at the end of two months no infection was obtained. At the end of ten days in one experiment, however, plants were inoculated and two cases of mosaic disease developed from a series of eight plants, but it is believed that this may possibly have been an accidental infection, as in no other instance was infection obtained. In formaldehyde, however, we have a compound which has a specific narcotic action on certain enzymes aside from its surface activities.

Where carbolic acid was added to a solution of the sap the active principle was apparently destroyed.

In chloralhydrate we have a substance very soluble in water, but not possessing any relatively great surface activity. It has, however, a specific toxic action on the causal agent of the disease, and even after twenty hours no infection was obtained. These results with chloralhydrate are in complete accord with those obtained in the enzyme work previously mentioned.

Most of the substances used in the above experiments possess a very definite toxic action to all organisms, particularly bacteria and fungi. As to their effect on the so-called ultramicroscopic organisms the writer is unable to state, not having had the opportunity of working with so-called cultures of these organisms. The parallelisms between the surface-tension effects of these substances on enzymes and on the sap containing the active principle of the mosaic disease are very striking.

Having shown that the causal agent is not bacterial or fungous in character, we must eliminate for the present the supposition of the presence of a toxin or virus in the pathologist's conception of these terms, as it is usual to conceive of these substances as being either the product of an organism or the activity manifested by the organism itself. As to the production of toxins and viruses by the so-called ultramicroscopic organisms little is known. Noguchi was the first to apparently demonstrate that such organisms do exist, and was able to cultivate an organism obtained from the brain of patients suffering from infantile paralysis.

However, these organisms were always mixed with certain bodies probably of a protein nature, and Noguchi, himself, so far has been unable to state absolutely which may be the active agent, although he naturally infers from his inoculation experiments that the organisms found must be the causative agent owing to the extreme infectious character of the disease. He, however, states that it is not absolutely clear to him whether the organism alone or a combination of this organism with the bodies found in culture associated with it are capable of producing infection. He does state, however, that in the case of *animal* pathology no such symbiotic relationship has so far been observed. From the character of his statement, however, it is clearly indicated that he does not preclude the possibility of such a condition arising.

Probable Character of the Causal Agent.

The question as to the exact character of the causal agent of mosaic disease has been an extremely interesting one to investigators, and studies on this phase of the problem have narrowed the field by the elimination from consideration of fungi and bacteria, as has previously been shown not only in this work, but also by many other investigators. This also precludes the presence of a virus or a toxin resultant from the activities of such organisms.

This leaves, then, for consideration as the causal agent an "ultramicroscopic" or "invisible" organism and the enzymic activities in their fullest conception. The reactions of the so-called "ultramicroscopic" organisms are little known at present, and about the only grounds for admitting of such a class of organisms is the *infection* factor, and possibly *reproduction* to a certain extent. We do know, however, many reactions of the class of substances called enzymes and toxins, but fundamentally the differentiation of the three above mentioned is difficult, and is perhaps in many cases impossible. Working with filtered sap from mosaic-diseased plants, we get the following results in comparison with reactions of some of the so-called "ultramicroscopic" organisms and toxins.

Temperature. — The sap containing the causal agent of mosaic disease becomes non-infectious; in other words, becomes inactive when heated to about 80° C. for a short time. It is reported that ultramicroscopic organisms and toxins are killed or rendered inactive, respectively, by exposure to heat for any length of time at temperatures somewhat below 100° C. Enzymes are also rendered inactive at temperatures somewhat below 100° C. All three react practically alike as regards temperature. The causal agent in mosaic sap, as may be seen, is also rendered inactive at temperatures below 100° C.

Size. — As to size, nothing can be definitely stated, but it is a fact that the ultramicroscopic organisms, enzymes and toxins must have a diameter of less than .1 μ, otherwise they would become visible under the higher powers of the microscope. In no case has it been possible to demonstrate the presence of organisms under even the highest powers available.

Reaction to Antiseptics. — It is stated that the ultramicroscopic organisms are not, to any extent, affected by the ordinary antiseptics, and the same is true for toxins in general. On the other hand, enzymes and their activities are very strongly affected by the substances usually made use of as antiseptics, and this is found to be true, with one or two possible exceptions, in the case of mosaic sap. It has been shown that formalin, carbolic acid, chloralhydrate, and even chloroform in excess, will inhibit the activities of the causal agent in mosaic sap, while, on the other hand, such substances as ether, toluol, thymol and chloroform in dilution have little or no effect. While all three classes are to a certain extent affected by antiseptics in general, the enzyme group is most strongly affected, and in the case of the mosaic we find this reaction; also, as has been pointed out, the effect of substances possessing marked surface-active properties is, in the case of mosaic sap, quite analogous to that of these substances on enzymes. It had been hoped to carry on more detailed work on this point, but as yet no opportunity has offered to take up this phase of the matter. Allard[1] has studied the effects of alcohol, ether and other substances on mosaic sap, and an interpretation of his results, with particular reference to the surface-active properties of the substances under consideration by him, parallel the author's findings in the case of enzymes to a marked degree. It is believed that more work of this character might throw considerable light on this matter.

Activity. — So far as can be judged from laboratory results the activity of the causal agent in mosaic sap is continuous, and as this holds true not only for organisms but, within limits, for enzymes and toxins as well this property cannot be made use of for differential purposes.

"Koch's Laws" or "Postulates," so called, are followed by all three of the classes under consideration, and the same is true in the case of mosaic disease; the causal agent obeys these laws, and might well be placed in any one of the classes so far as this property is concerned.

The Kitasato filter has been used by some as a means of separation of "ultramicroscopic" organisms from enzymes and toxins, and although the arbitrary use of any one filter as a standard, unless the size of pores, adsorption properties, thickness of walls, etc., are carefully taken into consideration, may be open to question, this procedure has been followed in some instances in animal pathology, and it has been found that the Kitasato filter held back the organisms and that no infection could be obtained from the filtrate. In the case of the mosaic disease, however, we find that apparently, as has been previously indicated in this paper, where large volumes are used, the causal agent passes through the Kitasato filter, and we do get infection from the filtrate.

The disease is infectious, but whether the infection may be indefinitely transferred through several plants with undiminished virulence is open to question. On some varieties of tobacco this does not apparently take place, but so far as the writer's observations go the virulence of the causal agent is not lessened appreciably. This property is one of the strongest points advanced by those favoring the theory of the presence of a definitely organized parasite as the causal agent of the disease. It is, however, entirely possible that enzymes or similar substances introduced into a plant even in extremely small quantities, are capable of regeneration of a certain kind, and indeed it is held by some that enzymes do *grow* and even reproduce themselves under certain conditions. The difficulties encountered in the study of this phase of enzyme work are very great, however, and it is questionable if such statements can be as yet definitely accepted.

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[1] Allard, H. A.: Some properties of the virus of the mosaic disease of tobacco. Journal Agr. Research, Vol. VI., No. 17 (July, 1916).

Organisms, even of the ultramicroscopic class, in their reactions would not follow the law of proportionality, but in the case of mosaic sap and its reactions we find, by measuring the relative activities and reactions of the enzymes present that apparently a proportionality of reaction for any one lot of sap does hold. The writer has very often found in the measurement of the activities of the catalase and oxidase particularly that not only a fairly definite relation exists between the various enzymes, but that reaction of any one is dependent on the amount of sap used. Of course, here we are dealing with a mixture, and it may be open to question if the measurement of the enzyme activities is a true measure of the activities of the causal agent.

The whole subject of the differential diagnosis of enzymes, toxins and ultramicroscopic organisms is an extremely difficult one, and no sharply dividing lines can properly be drawn between them. It would appear to the writer that in some cases, at least, it is entirely dependent on the viewpoint and interpretation of the investigator as to the class to which certain diseases should properly be ascribed.

The factors of reproduction and infection, as ordinarily understood, have proved a stumbling block to the acceptance of the idea that there may be other forms of matter aside from organisms capable of reproducing a disease, but there is in reality very little real ground for taking this attitude. In the case of the mosaic disease there are certainly many reactions which will not allow of placing the causal agent in the class of ultramicroscopic organisms. The general distribution of the causal agent in a diseased plant, its exceedingly localized action on the meristematic tissues, this action being apparently confined to the nascent chlorophyll, the non-uniformity of response to apparently favorable conditions during any one season even on one field, and also its individualism as shown by plants growing together (one often diseased and the other not) are to the writer indicative of something of a different character.

It is also possible that in the search after the infinitesimal the fact that a highly organized plant as a whole may react in the same manner as some of the simpler organisms has been overlooked. It is as a rule not the presence of an organism alone which is responsible for the manifestations of disease, but the products of the metabolism of the organism.

If the metabolic processes are changed ever so slightly, due to any stimulus, far-reaching effects may be induced throughout the organism, and this we find to be the case in the mosaic disease, and the writer believes that it is justifiable to look upon the matter in this light, as it is no more hypothetical than the concept of an "ultramicroscopic" parasite, which, if demonstrated (and no amount of concentration or methods of culture have indicated in any way the presence of aggregates or colonies), certainly would become visible if multiplication occurred.

Theoretically is it possible to conceive of an organism, functioning as such, to be made up of so few molecules of protein, fat and carbohydrate that it would be impossible to demonstrate its presence? If so, our ideas of relative size of molecules of protein, etc., must be changed.

Prevention and Control.

The question of the prevention and control of mosaic disease is of prime importance to the grower, entirely aside from more technical considerations as to the exact cause or causes of the disease, and it is believed that with reasonable care it is possible for the grower to lessen materially the amount of mosaic in the field.

Many recommendations have been made regarding treatment of diseased plants after they have once contracted the disease, but so far the writer has never observed a plant which, once attacked by the disease, recovered at any subsequent period of its growth. On the other hand, it has never been observed that the disease killed a plant, at least in this region.

It is doubtful, owing to the character of the disease, if it can ever be entirely eliminated on some soils and under certain unfavorable conditions occurring during some seasons. As has been indicated previously there is apparently little or no relation to be found between excess or lack of food materials and the prevalence of the mosaic. It has been in some instances stated that favorable results have been obtained from the use of lime in different forms, but this treatment cannot be recommended for various reasons. Experimentally it has been shown that heavy liming has little or no effect on the disease once a plant has contracted the disease, and even when applied to soils from old beds no consistently favorable results have been obtained (see page 91). Used in the larger quantities it might be inferred from the results that the lime apparently did exert a beneficial action, but to apply lime generally in such amounts would be folly, as it would in many cases bring the soil to a comparatively neutral or alkaline condition, which reaction would favor the development of root rot, caused by the fungus, *Thielavia,* and this, once thoroughly established, in a field or seed bed, is much more injurious to tobacco than is the mosaic disease.

As has been pointed out, the writer, from his observations, is strongly of the opinion that much of the field infection may be traced to the seed bed, and as a rule those beds which have long been used or carelessly handled are found to be producers of mosaicked seedlings in far larger numbers than are found on new beds or on beds which have been carefully sterilized either by steam or formalin.

It has been found that the soils of old beds do tend to produce more mosaicked plants than do those of new beds, although it may be possible that under field conditions the differences in amount during different seasons may vary. Soils brought into the greenhouse gave the following results: —

TABLE XIV. — *Experiments with Soils from Old and New Beds.*

[Seedlings transplanted in sterilized soil.]

SOIL.	Number of Seedlings transplanted.	Number Diseased Four Weeks after Transplanting.	Diseased (Per Cent.).
Soil A (old bed),	60	45	75.0
Soil 21 (old bed),	43	17	40.0
Soil I*a*,	50	21	40.0
Soil B (new bed),	30	3	10.0
Soil C (new bed),	49	2	4.0

The soil from the old beds was in very bad condition and had been very carelessly handled, apparently.

A count of mosaicked seedlings left in these old-bed soils six weeks after the transplants was taken, showing, respectively, an infection of A, 43 per cent.; 21, 32 per cent.; I*a*, 17 per cent.; B, 6 per cent.; and C, 7+ per cent.

It is evident that some of the seedlings were infected during transplanting, probably by handling diseased seedlings and then healthy ones, thus transmitting the disease. This method of transmission at the time of transplanting is very common, as has been pointed out repeatedly.

It has been shown that much of our infection may originally come from the seed bed as a result of the soil becoming infected for any reason. The use of tobacco stems and tobacco water has also been found by many investigators to cause infection. The amount of infection resulting from watering beds with water extract of diseased stems is, however, problematical, and it is not believed by the writer that this is an important factor in mosaic transmission, especially if the stems are steeped in hot water. The broken, decaying roots of diseased plants left in the beds also carry the causal agent of the disease as do the stems of diseased plants, and freezing has apparently little or no effect on it, so the use of stems on the seed bed should be carefully attended to in order not to apply any from diseased plants. Where stems and tobacco water are applied year after year without attention to this point the bed usually becomes more seriously infected.

One of the cheapest methods for the control of this disease in the seed bed, where it can be advantageously carried out, is to change the location of the beds to soil on which no tobacco has been grown, and to avoid the use of stems and tobacco water. Occasionally, however, some slight infection will occur even here, but as a rule not to any great extent. If proper attention is paid to watering, ventilation, etc., little trouble of this character is to be expected in new seed beds.

It has been shown in Connecticut and elsewhere that a thorough sterilization of the seed bed by steam at a boiler pressure of from 70 to 90 pounds is also a satisfactory method for the control not only of fungous diseases but weeds also, and the same holds true for the mosaic disease. The writer has seen this tried a number of times with excellent results where the above-mentioned pressures have been used. Some growers, however, seem to be of the opinion that the prime value of steaming is to kill weed seeds, and so use low pressures. While low pressures will kill weed seeds, it is questionable if they will sterilize the soil sufficiently to kill the spores of fungi or render inactive the causal agent of the mosaic, although under laboratory conditions it is rendered inactive at temperatures of about 80°C, equivalent to 176°F. In some of our experiments conducted some years ago it was strongly indicated that improper partial sterilization would not entirely rid the soil of the causal agent of mosaic.

It might be stated here that, in many cases where the growers have reported failure in the control of diseases after steam sterilization, inquiry has usually brought out the fact that too low pressure was used, and as a result thorough sterilization was not obtained. Another source of failure of beds after sterilization with steam, under high pressure, has been that the grower has not paid sufficient attention to watering. This matter should be closely attended to, as a sterilized bed, particularly on light soils, dries out very quickly, and needs much more attention than is usually given a bed under ordinary conditions. If the watering is neglected there is very often a severe checking of the germination of the seed, and in some cases a partial loss of the bed.

Formalin sterilization may also be used, and is quite as satisfactory, especially when used on light soils. On heavy soils it is not quite so convenient to apply, however. Where formalin is used the beds cannot be sown until all the formalin is out of the soil, which usually takes from ten days to two weeks. This very often is too long a delay, particularly where spring sterilization is practiced.

It has been pointed out that the workmen may be a rather important factor in transmitting the disease (page 88), and in cases where at transplanting time diseased seedlings are handled it has been recommended by Clinton[1] that the hands be thoroughly washed in soap and water before again handling healthy seedlings. If these precautions are taken, according to Clinton, a considerable amount of mosaic infection will be avoided at the time of planting.

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[1] G. P. Clinton: Chlorosis of Plants with special reference to Calico of Tobacco. Conn. Agr. Exp. Sta. Rept., 1914, p. 417.

It has been repeatedly shown that care should be exercised during early cultivation not to cut the roots or touch broken or abraded leaves of plants and then subsequently touch other plants, for the disease is very easily transmitted in this way, as the fine hairs or epidermis may be broken and infection occur. The amount of infection due to cultivation is, however, in the writer's opinion, slight, but as much care as is commensurate with efficiency should be exercised by the workmen during cultivation.

The advisability of the removal of diseased plants is open to question, and on the whole it cannot be economically recommended unless the plants can be replaced early in the season. As has been previously pointed out, the disease may be carried from plant to plant when topping, etc., and the subsequent sucker growth will become mosaic. At this time, however, the commercial leaves are of such size that their value will not be materially impaired, but if possible, to prevent a certain amount of infection, only healthy or diseased plants should be topped at any one time. Of course, all suckers developing later, diseased or otherwise, should subsequently be removed from all plants, not only for the sake of the commercial leaves, but to prevent a ragged looking field, giving the appearance of a large amount of mosaic.

It has been very difficult to associate any particular type of soil with general occurrence of mosaic disease, but on the whole, from data gathered at different times, the heavier types of soil in the valley appear to be more generally favorable for the production of mosaic-diseased plants. This cannot be definitely stated, however, as the data are complicated by the fact that in some cases, on both heavy and light soils, the condition of the soil as regards organic matter present enters into the question. The writer has observed that on many heavy soils where comparatively large amounts of organic matter are present during certain seasons, in comparison with similar soils deficient in organic matter, the mosaic is much less. To a certain extent this holds true also for the lighter soils. The exact relation existing between the mosaic disease and these factors is at present not enough studied to warrant definite conclusions, but Sturgis (*loc. cit.*) was of the opinion that clayey soils were favorable to its production. It is a significant fact that many of our tobacco soils are somewhat deficient in organic matter, however. Well-cultivated and consequently well-aerated soils do not apparently produce as many mosaicked plants as those which are not well cultivated.

Another factor which should be carefully attended to is that of the moisture conditions in the bed at the time the plants are pulled. It should not be too moist nor too dry, as in either case the roots are apt to be broken and infection from handling result more certainly than when the plants are removed with a minimum of root injury.

SUMMARY.

1. The mosaic disease is not caused by fungi or bacteria. It has never been possible to demonstrate the presence of these organisms in the tissue of any part of the plant.
2. The disease is highly infectious, particularly when inoculated into young plants, all subsequent growth exhibiting marked symptoms.
3. The disease is not contagious.
4. Until more is known about the action of the so-called "ultramicroscopic" organisms, the disease cannot be ascribed to an organism of that class, as the character and reactions of the causal agent do not in many respects coincide with reactions of that class of organisms.
5. Many of the reactions of the causal agent are of such a nature as to indicate that it is either an enzyme, an aggregate of enzymes, or the product of enzyme activities.
6. The enzyme activities of diseased plants are greatly altered, far more than is usually the case in plants which are attacked by pathogenic fungi or bacteria.
7. As a result of the writer's experiments, it is believed that the disease is primarily induced by a disturbance in the enzyme activities and their relation to each other, due to abnormal metabolism, and not by any parasite.
8. The pathogenicity of a disease is not necessarily a proof that it is of parasitic origin, as it is conceivable that similar conditions may exist relative to enzyme activities, although the extent of such action is not known at present.
9. On fields where the mosaic disease is prevalent, the primary infection can usually be traced to the seed bed, and many healthy seedlings are infected by the workmen when setting the plants. It is estimated that about 80 per cent. of the infection occurs in this manner.
10. Owing to the nature of the disease the matter of absolute prevention and control is difficult, but with careful attention to details of sterilization of the seed bed, and handling of the plants at time of transplanting, a large percentage of infection may be avoided.

BULLETIN No. 176 OCTOBER, 1917

MASSACHUSETTS
AGRICULTURAL EXPERIMENT STATION

The Cause of the Injurious Effect of Sulfate of Ammonia when used as a Fertilizer

By R. W. RUPRECHT and F. W. MORSE

This Bulletin is a continuation of Bulletin No. 165, "The Effect of Sulfate of Ammonia on Soil." It shows that soluble salts of iron, manganese and aluminium, severally or collectively, were always found in soils which had been dressed with sulfate of ammonia without an addition of lime, and that these several compounds were positively injurious to clover seedlings in cultural experiments.

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[1] On leave on account of military service.

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Publication of this Document
approved by the
Supervisor of Administration.

BULLETIN No. 176.

DEPARTMENT OF CHEMISTRY.

THE CAUSE OF THE INJURIOUS EFFECT OF SULFATE OF AMMONIA WHEN USED AS A FERTILIZER.[1]

BY R. W. RUPRECHT AND F. W. MORSE.

PART I. — CHEMICAL INVESTIGATIONS.

In a previous report[2] there has been described how the continued use of sulfate of ammonia on the experiment plots called "Field A" caused the removal of lime in the drainage waters in the form of calcium sulfate, and when lime was not present in sufficient quantity there were formed noticeable amounts of aluminium sulfate and iron sulfate, but that no accumulation of free acid could be found.

Since comparatively little material had been published on the formation of salts of aluminium and iron in soils, it was considered advisable to continue the investigations, and as the work progressed it was found that soluble manganese salts were also present in some of the soils to which sulfate of ammonia had been applied.

The present bulletin is a report of our investigations into the relations between sulfate of ammonia and salts of aluminium, iron and manganese, and the quantities of these salts which will injure clover seedlings.

Soils from plots 1, 6, 7 and 8 of Field A were used to determine how freely ammonium sulfate solutions would extract manganese from them. The soils have been fully described in Bulletin No. 165, but for convenience the fertilizers used on these four plots will be described here.

Each plot received dissolved boneblack at the rate of 500 pounds per acre, and muriate of potash 250 pounds per acre. Plot 1 received 300 pounds of nitrate of soda per acre; plots 6 and 8 received 225 pounds of sulfate of ammonia per acre; and plot 7 received no nitrogenous fertilizer. In 1909, and again in 1913, hydrated lime was applied to one-half of Field A, crosswise of the plots. The total amount in the two dressings was 9,000 pounds per acre.

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[1] The work reported in this bulletin, together with the material published in Buls. Nos. 161 and 165, was submitted by Mr. Ruprecht to the faculty of the graduate school of the Massachusetts Agricultural College in part fulfillment of the requirements for the degree of doctor of philosophy.

[2] Bul. No. 165, "The Effect of Sulfate of Ammonia on Soil."

The ammonium sulfate solutions were used in the manner described in Bulletin No. 165, viz.: 150 grams of air-dry soil were placed in a large flask with 750 cubic centimeters solution and shaken frequently for two hours. The solution was then filtered through paper, which gave a clear filtrate with a yellowish tint.

Manganese was determined by the colorimetric method described by Schreiner and Failyer,[1] in which the manganese salts are oxidized to permanganate by nitric acid and lead peroxide.

The strengths of the solutions were tenth-normal (N/10) and normal (N). The results obtained by the extracts from unlimed soils are tabulated in Table I., together with the amounts of iron obtained from the same soils in our previous work, and reported on page 81 of Bulletin No. 165.

TABLE I. — *Milligrams Manganese Oxide* (Mn_3O_4) *and Iron Oxide* (Fe_2O_3) *obtained from 100 Grams Air-dry Soil by Ammonium Sulfate Solution.*

PLOT.	MANGANESE OXIDE.		IRON OXIDE.	
	N/10 Solution.	N Solution.	N/10 Solution.	N Solution.
1, ...	Trace.	.58	.40	.79
6, ...	.88	1.52	.46	.51
7, ...	Trace.	1.18	.43	.50
8, ...	.63	1.45	.89	1.21

The stronger solution removed much more manganese than the weaker, but not in proportion to its strength. The fertilization of plots 6 and 8 with ammonium sulfate evidently produced some manganese compounds that were readily soluble in the solutions, since there was more manganese obtained from those plots than from the other two.

From the limed soils of these four plots there was removed no manganese by N/10 or N solutions, but when stronger solutions of ammonium sulfate were used (2½ N and 5 N), traces of manganese were found in the soil extracts. This would appear to be due to the presence of enough ammonium sulfate in the concentrated solutions to overcome the lime and act upon the manganese in the soil.

Since iron had been found by color tests to be generally present in water extracts from the unlimed soils of Field A, while aluminium could rarely be detected by the precipitation test with ammonium hydroxide, it was decided to try larger quantities of soil and larger volumes of water, which would permit subsequent concentration and perhaps yield measurable quantities of these elements by the usual analytical methods.

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[1] Bul. No. 31, Bureau of Soils, U. S. Dept. Agr., 1906.

Eight kilograms of air-dry soil were put in a percolation jar, the tubulure of which was covered with a piece of linen and plugged loosely with glass wool. Enough water was added to saturate the soil, which was then left in the wet condition for two days. Water was then added in portions of 1 liter at a time, each of which ceased dropping from the bottom of the jar before another was added. Eight liters were thus used, and the percolated water was evaporated in a porcelain dish on the water bath until the volume was reduced to 1 liter, which was next filtered through paper and finally through a porcelain filter under pressure, as there was a turbidity which paper would not remove.

The clear soil extract was next heated and made slightly alkaline with ammonium hydroxide. A copious flocculent precipitate formed, which was collected on a filter, washed and then analyzed. When the filtrate was further heated and a few drops of ammonia added, a second precipitate, similar to the first, formed and was also analyzed. The two precipitates differed but little in composition, and the results obtained were combined in Table II.

TABLE II. — *Constituents of Precipitate obtained in Concentrated Soil Extract, expressed as Milligrams in 100 Grams of Soil.*

	Plot 1.	Plot 6.	Plot 8.
Aluminium oxide (Al_2O_3),	.074	.152	.105
Silica ($Si\ O_2$),	.381	.538	.835
Manganese oxide (Mn_3O_4),	None.	1.596	.362
Calcium oxide ($Ca\ O$),	1.955	None.	.225

The precipitate was found to contain but a trace of iron, which is not tabulated as such, but is really included in the aluminium oxide. The calcium which separated in the ammonium hydroxide precipitate was apparently in the form of carbonate, as the precipitate from the extract of plot 1 effervesced vigorously when dissolved in hydrochloric acid, as the first step in analysis.

There is a striking difference between the precipitate obtained in the soil extract from plot 1 and those from plots 6 and 8. The protective effect of nitrate of soda on the calcium in the soil is shown in contrast to the depleting influence of ammonium sulfate, with the consequent formation of salts of manganese and aluminium. No effort was made to estimate possible calcium or manganese not precipitated by the successive additions of ammonium hydroxide.

A second series of percolation experiments was tried in which but 1 kilogram of soil was used, and proportionately smaller amounts of water were percolated through it, until the total percolate amounted to 1 liter. The percolate was filtered through porcelain and subsequently yielded no precipitate with ammonium hydroxide.

Iron and manganese were both found and determined by the colorimetric methods. Both limed and unlimed soils from plots 1, 6, 7 and 8 were used in this series. All the extracts yielded colorimetric tests for iron, but only those from the unlimed soils showed any manganese. The results on the unlimed soils are given in Table III.

TABLE III. — *Milligrams Manganese Oxide* (Mn_3O_4) *and Iron Oxide* (Fe_2O_3) *removed in Water from 100 Grams of Unlimed Soil.*

	Plot 1.	Plot 6.	Plot 7.	Plot 8.
Manganese oxide,	Trace.	1.49	.49	.47
Iron oxide,	.04	.07	.09	.06

The amounts of manganese from the soils of plots 1, 6 and 8 are closely like those obtained in the previous series with 8 kilograms of soil.

The iron obtained is about one-half the amount of aluminium oxide tabulated in the previous series.

There were in the laboratory samples of soil from plots 5 and 6 which were collected four years before, in 1912. Plot 5 had received the same amount of sulfate of ammonia that had been applied to plot 6. Both samples were from the unlimed halves of the plots. One kilogram of each was treated as in the previous experiment. The extracts showed the presence of aluminium and iron, but were most striking in the tests for manganese. Plot 5 yielded 2.36 mg. Mn_3O_4, and plot 6 yielded 3.18 mg. Mn_3O_4, from 100 grams of soil. This shows that the formation of salts of aluminium, iron and manganese by ammonium sulfate was as marked four years ago as in 1916.

All these experiments showed that ammonium sulfate persistently formed soluble salts of aluminium, iron and manganese in the soil of Field A.

It was next decided to secure samples of soils from other fields that had received ammonium sulfate as a fertilizer over a considerable period of time. The desired soils were obtained from the agricultural experiment stations of Ohio and Rhode Island by the kindly co-operation of Director Thorne and Director Hartwell.

The soil of the Ohio experiment field is a rather heavy clay loam. The samples were taken from Section C of the continuous five-year rotation experiment described in Circular No. 144 of the Ohio Agricultural Experiment Station. The plots selected for our purpose were Nos. 8 and 24.

Since 1893 each plot had received acid phosphate and muriate of potash, but plot 8 had not received any nitrogenous fertilizer, while plot 24 had been dressed with sulfate of ammonia at the rate of 220 pounds per acre during each five-year period. One-half of each plot had received ground limestone annually at the rate of 2 tons per acre since 1908, while the other half had received none during that period.

The plots were seeded with clover at the time the soil samples were taken in the fall of 1915.

In a letter regarding the samples, Director Thorne said: —

> For several years there has been practically no clover on the unlimed ammonium sulfate plots in our work. There are occasionally a few scattering plants, but probably not 20 plants on the twentieth-acre plot. . . . When ammonium sulfate is neutralized with lime we get a luxuriant growth. . . . There are usually at the beginning of the season as many clover plants on the unlimed as on the limed land, but they do not get much beyond the nutriment furnished by the seed, and by harvest have disappeared.

The soil of the Rhode Island experiment field is a sandy loam. The samples for our use were taken from the permanent plots numbered 23, 25 and 29, which have been repeatedly described in the annual reports of the Rhode Island Agricultural Experiment Station.

All three plots have received acid phosphate and muriate of potash since 1893. Plots 23 and 25 have been supplied with nitrogen in sulfate of ammonia, while plot 29 has had nitrate of soda. Plots 25 and 29 have at irregular intervals received applications of lime, and in 1915 all three plots received a dressing of it, but in different amounts. Plot 23 received the equivalent of 500 pounds calcium oxide per acre, plot 25 received 1,500 pounds, and plot 29 received 1,000 pounds. This application of 500 pounds per acre on plot 23 was the first in its history, and was made, as Director Hartwell stated, ". . . because it was becoming so very unsuitable for crop growth."

The soils were prepared for investigation by drying them at a moderate temperature, and then sifting them through a coarse screen with seven meshes to the linear inch, which is the same treatment that was used with the soils from Field A.

The samples from Rhode Island were used in percolation experiments with quantities of 1 kilogram of soil and 1 liter of percolated water.

The clay of the Ohio soils rendered this method impracticable because the water percolated very slowly. The Ohio samples were accordingly put in stoppered bottles, with twice as much water as there was soil by weight, and shaken continuously for two hours in a machine. The solutions were first filtered through paper and finally through porcelain filters.

Aluminium, iron and manganese were tested for, and when present in measurable quantities their amounts were determined.

Aluminium could not be obtained in appreciable quantity from any but the soil from plot 23 of the Rhode Island field. No manganese was found in the extracts from any Rhode Island sample, but was obtained from all the Ohio samples. Iron was extracted from all but the more heavily limed soils.

TABLE IV. — *Milligrams of Aluminium Oxide (Al_2O_3), Iron Oxide (Fe_2O_3), and Manganese Oxide (Mn_3O_4) removed in Water from 100 Grams of Soil.*

[Soils representing Ohio and Rhode Island experiments with ammonium sulfate.]

	Aluminium Oxide.	Iron Oxide.	Manganese Oxide.
Ohio plot 8, limed,	None.	Trace.	Trace.
Ohio plot 8, unlimed,	None.	.05	.16
Ohio plot 24, limed,	None.	None.	.03
Ohio plot 24, unlimed,	None.	.03	.64
Rhode Island plot 23,	3	.27	None.
Rhode Island plot 25,	None.	Trace.	None.
Rhode Island plot 29,	None.	None.	None.

The Ohio soil which had received sulfate of ammonia (plot 24) without lime gave a striking reaction for soluble manganese salts similar to our own soils; but in the soils from Rhode Island the sulfate of ammonia seemed to exert its influence on aluminium and iron compounds (plot 23).

At a later period samples of soil were received from Prof. F. D. Gardner of Pennsylvania State College, which were taken from different plots on the permanent experiment field at that institution. The soil of the field is a clay loam. The samples were taken from plots 31, 32 and 36.

Plots 31 and 32 had received equal amounts of dissolved boneblack and muriate of potash. Plot 31 had sulfate of ammonia applied at the rate of 240 pounds per acre every two years, while plot 32 received 360 pounds per acre in the same period. Plot 36 received no fertilizer. This treatment had been in vogue since 1885.

One kilogram of air-dry soil was treated with water by the percolation method.

Plot 32 with the heavier application of ammonium sulfate yielded strikingly more iron and a little more manganese than plot 31.

The unfertilized soil, plot 36, yielded the most iron, but a negligible amount of manganese.

TABLE V. — *Milligrams of Iron Oxide (Fe_2O_3) and Manganese Oxide (Mn_3O_4) removed in Water from 100 Grams of Soil.*

[Soils representing Pennsylvania experiments with sulfate of ammonia.]

	Plot 31.	Plot 32.	Plot 36.
Iron oxide, ...	.28	.58	.82
Manganese oxide, ...	.13	.15	.01

The results of the chemical investigation of the effect of sulfate of ammonia as a fertilizer in constant use on soils of four different experiment fields show the accompaniment of soluble salts of either aluminium, iron or manganese, or all three together, in the absence of a base like lime. In the presence of calcium carbonate, water has removed no observable amounts of aluminium or manganese salts, and bare traces of iron salts, indicating that lime either reacts with the ammonium salt promptly, or subsequently breaks up the salts of aluminium and manganese, and also iron salts, almost completely.

PART II. — WATER CULTURES.

Our investigation of the effects of sulfate of ammonia on the soils of Field A included in its progress several series of water cultures in which seedlings of rye, barley and clover were used to study the possibilities of poisonous effects from the presence of soluble substances in the soils. In the earliest series there were used water extracts made from soils of plots 1, 6, 7 and 8 for the purpose of learning whether the injurious effect of ammonium sulfate applied to the soil would appear in the solution obtained from the soil.

The soil extracts were prepared in sufficient quantity by mixing soil and water in the proportion of 1 part by weight of soil to 2 parts of water, shaking frequently during a period of two hours, and then allowing the liquid to clear by settling. The water extract was then carefully decanted from the soil. A part of this extract was filtered through porcelain, under pressure, to see whether the poisonous substances, if present in the extract, were colloidal in their nature.

Discs of paraffine, reinforced by wire gauze and punctured with numerous holes, were arranged by means of suitable corks to float on a basin of water flush with the surface. On these discs the seeds were moistened sufficiently to germinate, and their radicles then penetrated through the holes into the water below. The plan was essentially that described in Bulletin No. 70, Bureau of Soils.

As soon as the seedlings were large enough for the purpose, selected ones were transferred to wide-mouthed bottles, which contained the soil extracts. Each bottle contained 250 cubic centimeters, and 4 seedlings were supported in each one through notches cut in the cork stopper. The different series were grouped as follows: —

PLOT 1.

Rye Seedlings.

Unlimed soil, unfiltered extract.
Unlimed soil, filtered extract.
Limed soil, unfiltered extract.
Limed soil, filtered extract.

Clover Seedlings.

Unlimed soil, unfiltered extract.
Unlimed soil, filtered extract.
Limed soil, unfiltered extract.
Limed soil, filtered extract.

The same arrangement was maintained for the soils of plots 6, 7 and 8, and each extract was tested in three different bottles with a total of 12 seedlings. The cultures were maintained for four weeks, at the end of which the seedlings had begun to wilt.

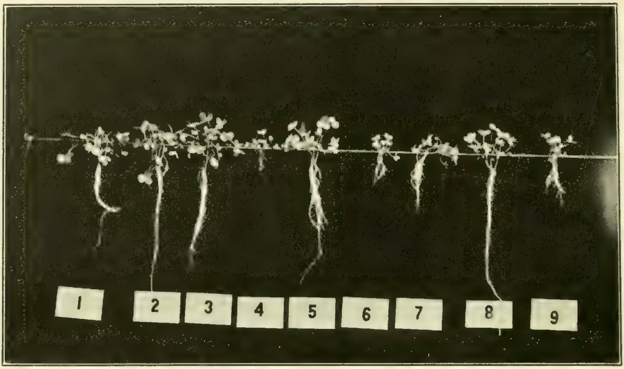
Differences in the seedlings were noted by the end of the first week. Those growing in the extracts from the limed soils were noticeably better as a whole than those in extracts from unlimed soils. Rye seedlings in the unlimed extracts had reddish stems and grew less rapidly. Roots of the clover seedlings in unlimed extracts began to appear stunted; especially so in the unlimed extracts from plots 6 and 8. When the experiment was discontinued the best seedlings had developed in the extracts from the limed soils of plots 6 and 8, while the poorest plants were in the extracts from the unlimed soils of the same two plots. The roots of the clover in these two extracts were short and thick and lacked branches. Filtered extracts produced the same results as unfiltered ones.

A lot of barley seedlings was next used in the unfiltered soil extracts. At the end of the first week the roots in the unlimed extract from plot 6 began to look stunted. By the end of two weeks the seedlings in all the unlimed extracts showed a tendency to wilt and the tips of the leaves turned white. At the end of the fourth week, when the experiment was stopped, the seedlings in the extracts from the limed soils were uniformly superior to those in the extracts from the unlimed. The poorest seedlings were in the extract from the unlimed soil of plot 6.

The strikingly inferior growth of the different kinds of seedlings in the extracts from the unlimed soils of plots 6 and 8, which had been dressed with ammonium sulfate, suggested that the poisonous effect might be due to sulfates of aluminium, iron or manganese, which were known to occur in extracts from those soils.

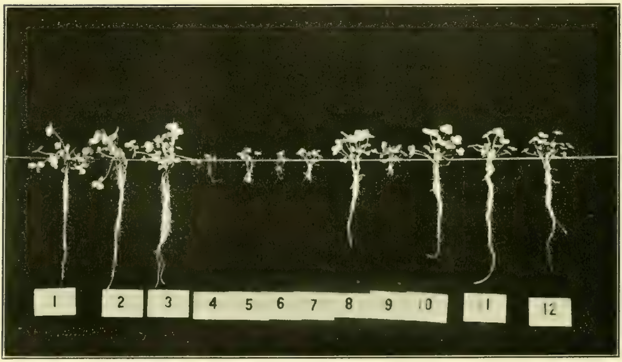
More culture experiments were accordingly tried from time to time, in which standard nutrient solutions were used instead of soil extracts. Vari-

PLATE I.



No. 1, Nutrient sol.; No. 2, Nutrient sol.+$CaCO_3$; No. 3, Nutrient sol.+$CaSO_4$; No. 4, Nutrient sol.+2 c.c. Al sol.; No. 5, same as No. 4+$CaCO_3$; No. 6, same as No. 4+$CaSO_4$; No. 7, Nutrient sol.+1 c.c. Al sol.; No. 8, same as No. 7+$CaCO_3$; No. 9, same as No. 7+$CaSO_4$.

PLATE II.



No. 1, Nutrient sol.; No. 2, Nutrient sol.+$CaCO_3$; No. 3, Nutrient sol.+$CaSO_4$; No. 4, Nutrient sol.+5 c.c. Fe sol.; No. 5, same as No. 4+$CaCO_3$; No. 6, same as No. 4+$CaSO_4$; No. 7, Nutrient sol.+2 c.c. Fe sol.; No. 8, same as No. 7+$CaCo_3$; No. 9, same as No. 7+$CaSO_4$; No. 10, Nutrient sol.+1 c.c. Fe sol.; No. 11, same as No. 10+$CaCO_3$; No. 12, same as No. 10+$CaSO_4$.

ous proportions of ferrous sulfate were added in one series, aluminium sulfate was used in a second series and manganous sulfate in a third.

The standard nutrient solution was prepared in two parts: (*a*) 20.5 grams manganesium sulfate in 350 cubic centimeters of water; and (*b*) 40 grams calcium nitrate, 10 grams potassium nitrate, 20.56 grams disodium phosphate in 350 cubic centimeters of water. From each of the solutions (*a*) and (*b*) were taken 100 cubic centimeters and added to 9,800 cubic centimeters of water, together with a few drops of ferric chloride solution. This diluted nutrient solution was used in the culture bottles.

Seedlings of red clover were used in all these experiments with nutrient solutions, because clover had shown the greatest susceptibility to the soil influences on Field A.

The experiments with sulfates of aluminium and iron have been fully described in Bulletin No. 161 of this station, and only a summary of the results is given here.

Effects of the aluminium and iron salts began to show by the end of the first week, in stunted, thickened roots, followed in a few days by a smaller growth of leaves, when compared with seedlings in the check nutrient solutions. Cultures with 43 parts of aluminium in a million, or with only 44 parts of iron, produced these effects, while in the higher concentrations employed the roots were killed.[1]

Calcium hydrate and calcium carbonate added to the bottles containing aluminium or iron neutralized their injurious effects in the lower concentrations, but were ineffective with high concentrations. Calcium sulfate was entirely ineffective as an antidote.

The poisonous effects of the salts appeared to be exerted upon the tips or growing parts of the roots. The rootlets died leaving a thick, stubby taproot. Microscopic examinations of the roots by Dr. G. H. Chapman showed the cells in the growing parts to be either killed or arrested in their development.

Photographs of the clover seedlings which were published in Bulletin No. 161 are reproduced here to show the characteristic effects of the poisonous sulfates of aluminium and iron.

Culture experiments in which manganous sulfate was added to the nutrient solutions in graduated quantities were begun after it had been demonstrated that ammonium sulfate fertilization was accompanied by soluble manganese salts in the soils to which no lime had been added.

A solution of manganous sulfate, $MnSO_4.4\,H_2O$, was prepared of $\frac{1}{10}$ molecular concentration, and measured amounts were made up to 250 cubic centimeters with the nutrient solution. Certain bottles received fine calcium carbonate and others calcium sulfate, so that the solutions in those bottles were approximately saturated with the calcium salt.

The scheme of the series is outlined below.

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[1] In preparing this bulletin it has been noted that in Bul. No. 161, by an unfortunate error in the decimal point, all figures relating to parts per million of iron in the nutrient solutions are only one-tenth as large as they should be. This error caused iron to appear much more toxic than aluminium, as compared in the tables of that bulletin.

No. 1. Standard nutrient solution.
No. 2. With calcium carbonate.
No. 3. With calcium sulfate.
No. 4. With 40 parts manganese per million of solution.
No. 5. With 40 parts manganese and calcium carbonate.
No. 6. With 40 parts manganese and calcium sulfate.
No. 7. With 100 parts manganese per million of solution.
No. 8. With 100 parts manganese and calcium carbonate.
No. 9. With 100 parts manganese and calcium sulfate.
No. 10. With 200 parts manganese per million of solution.
No. 11. With 200 parts manganese and calcium carbonate.
No. 12. With 200 parts manganese and calcium sulfate.
No. 13. With 300 parts manganese per million of solution.
No. 14. With 300 parts manganese and calcium carbonate.
No. 15. With 300 parts manganese and calcium sulfate.

The experiment was conducted outdoors in the pot yard instead of in the greenhouse, the seedlings being put under cover at night and during inclement weather. The experiment was continued four weeks.

The effect of the manganese was noticed after the first week. The seedlings with manganese did not grow as fast as the checks, and also began to show chlorosis of the leaves. The roots did not have a stunted appearance as was noticed when iron and aluminium salts were used, but seemed to be simply underdeveloped. Neither the presence of calcium carbonate nor calcium sulfate had any beneficial effect. In some cases the calcium carbonate seemed to aggravate the toxicity rather than alleviate it. When the experiment was discontinued the tops in the most concentrated manganese solutions had died and those in the most dilute had apparently lost all their chlorophyl.

The tops and roots of the plants were dried and manganese determinations were made on them. The table shows the amounts of manganese found in 1 gram of oven-dried samples.

TABLE VI. — *Milligrams of Manganese Oxide (Mn_3O_4) in 1 Gram of Clover Plants.*

	Tops.	Roots.
Standard,	None.	None.
40 ppm Mn,	2.01	17.94
100 ppm Mn,	4.56	58.80
200 ppm Mn,	5.02	83.90
300 ppm Mn,	4.41	75.31

The results show that manganese is taken up by the plants in considerable amounts and is carried into the tops. Concentrations above 100 parts of manganese per million of solution have little effect in increasing the amount taken up by the plant. While some manganese is carried into the tops, most of it remains in the roots.

In order to determine whether calcium carbonate or sulfate had any beneficial action in more dilute solutions of manganese a second experiment was undertaken. In this series 10 parts and 20 parts of manganese in a million parts of nutrient solution were, respectively, compared with the standard and with equal amounts of manganese supplemented by calcium carbonate and by calcium sulfate.

At the end of three weeks all the seedlings except those in the standard solution showed chlorosis by the light green or yellowish color of the leaves. The more dilute manganese still had a detrimental effect on the clover plants, but not so marked as in the previous experiments with higher concentrations. Neither of the calcium compounds exerted any beneficial effects, but as in the first experiment seemed, if anything, to increase the injury.

A third series of cultures was conducted during the winter in the greenhouse, and concentrations of from 10 parts to 40 parts of manganese per million of nutrient solution were again tried with and without calcium carbonate added to the solution. Much cloudy weather caused an inferior growth of the clover plants, but the experiment was continued four weeks, and at the end there was the same chlorosis of the leaves when manganese was present. Again, calcium carbonate failed to prevent the chlorosis in the presence of manganese, and instead apparently increased it.

Masoni,[1] Pugliese[2] and Aso[3] have found that iron salts seem to counteract the toxicity of manganese. In order to confirm their conclusions one series of experiments was undertaken using a combination of these two salts, another series using manganese plus aluminium salt, and still another series using iron and aluminium together.

To the standard nutrient solution were added 20 parts of manganese and 2 different quantities of aluminium, 21.6 parts and 43 parts, respectively, per million of solution, with and without calcium carbonate. A similar series was prepared containing 22 and 44 parts of iron per million, respectively.

All the solutions containing iron produced seedlings with darker color than the rest. The roots in the solutions containing aluminium or iron became stunted in appearance whether calcium carbonate was present or not. Manganese and aluminium or iron had no apparent antagonistic effects when present together in a nutrient solution.

This toxicity with calcium carbonate is unlike the results reported by McCool,[4] who found that calcium chloride would counteract the toxicity of manganese to a marked extent. This may be due to the difference in the solutions and seedlings used, as he used manganese chloride, calcium chloride and Canada field peas.

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[1] Staz. Sper. Agr. Ital. 44 (1911), p. 85; Abs. E. S. R. 26.

[2] Atti R Ist Incoragg. Napoli 6 ser. 65 (1913), p. 289; Abs. Chem. Abs. 9, p. 641.

[3] Bul. Agr. College, Tokyo, V. p. 177.

[4] Cornell Agr. Exp. Sta. Memoir No. 2 (1913).

Having found that manganese is carried up into the tops of the plants the following experiments were tried to determine if there was an increase in the amount of manganese in the tops of clover grown on plots where the poor vegetation was thought to be due to manganese.

The first crop of clover analyzed was the same as that reported in Bulletin No. 161. The tops only were analyzed, and the results were based on dry matter.

TABLE VII. — *Milligram of Manganese Oxide* (Mn_3O_4) *in 1 Gram of Clover.*

PLOT.	Fertilizer.	Limed Soil.	Unlimed Soil.
1,	Nitrate of soda,	Trace.	.076
5,	Sulfate of ammonia,	.054	.193
6,	Sulfate of ammonia,	.054	.193
7,	None,	.031	.114
8,	Sulfate of ammonia,	Trace.	.171

The clover from the limed portions of the plots shows very little difference between the different plots. The plants from the unlimed portions show a marked increase of manganese in those plots receiving sulfate of ammonia.

In the spring of 1915 samples of clover, grass, clover roots, and grass roots were taken from the limed and unlimed portions of plot 5.[1] From the unlimed end two samples were taken, one of normal looking plants and another of poor plants. The plants were brought into the laboratory and the roots carefully washed free of soil, especial care being taken not to break many of the finer roots. The tops were then cut from the roots, and the clover separated from the grass, the same being done with the roots. They were then dried at 75 degrees and ground. The tops were then analyzed for iron, manganese and silica. The roots were only analyzed for manganese as it is almost impossible to wash them entirely free from soil which would invalidate the results for iron and silica.

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[1] Plot 5 is fertilized as follows: $(NH_4)_2SO_4$, dissolved boneblack, low-grade sulfate of potash.

TABLE VIII. — *Composition of Clover and Grass Tops and Roots, in Milligrams per 1 Gram of Dry Sample.*

	Iron Oxide Fe_2O_3.	Manganese Oxide Mn_3O_4.	Silica SiO_2.
Plot 5, limed clover tops,	.63	Faint trace.	1.72
Plot 5, limed grass,	–	.053	19.25
Plot 5, unlimed good clover,	1.14	Trace.	4.82
Plot 5, unlimed good grass,	1.91	.158	26.64
Plot 5, unlimed poor clover,	1.34	.096	5.36
Plot 5, unlimed poor grass,	2.97	.272	57.35
Plot 5, limed clover roots,	–	Trace.	–
Plot 5, limed grass roots,	–	.138	–
Plot 5, unlimed good clover roots,	–	.091	–
Plot 5, unlimed good grass roots,	–	.218	–
Plot 5, unlimed poor clover and grass roots,	–	.245	–

A study of the table shows that the manganese is taken up to a greater extent by the poor plants, both clover and grass, than by the good plants. The grass seems to be more tolerant than the clover, much more being taken up than by the clover. The results would also seem to indicate that the manganese was not evenly distributed throughout the plot, but was more concentrated in spots. As it was rather difficult to find normal clover on the plot it might be said that the spots of better plants were the places of smaller amounts of manganese. A somewhat similar condition has been found by Guthrie and Cohen[1] on a golf green.

The variations in the iron content of the good and poor plants are so small as to come within the limit of experimental error. The increased amount of silica in the poor plants is probably due to their more mature state.

As the foregoing experiments with manganese salts in nutrient solutions had shown that calcium carbonate did not counteract the toxicity of the manganese, while in the field an application of lime to soil supposedly infertile because of the presence of manganese salts corrected the toxicity, pot cultures were started to determine whether calcium carbonate in the soil could counteract the toxicity of manganese.

The soil used was from the unlimed end of plot 7 and the unlimed end of plot 6. As the soil from the unlimed end of plot 6 already contained a large amount of soluble manganese it was first extracted by shaking it for two hours on a mechanical shaker with a volume of water twice that of the soil. The soil was then air-dried and passed through the large sieve (7 holes to the linear inch).

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[1] Agr. Gaz. New South Wales, 21 (1910).

Earthenware pots 6 inches in diameter and 5 inches deep were used. Each pot was filled with 2 kilos of the air-dried soil. The lime was applied to the surface and thoroughly worked in. The manganese sulfate was applied in solution. The soil was kept at a 25 per cent. moisture content. The clover seed was first soaked for eight hours in a solution of calcium hypochloride, and then seeded on the surface of the soil and pressed into contact with it. The soil was then covered with a half-inch layer of washed quartz and sand to act as a mulch. The treatment employed is shown in the table, there being two pots in each treatment.

The Series of Pot Cultures.

Pot.	Plots.	Soil Treatment.
1	Plot 6, . . .	None.
2	Plot 6, . . .	2 tons calcium carbonate per acre.
3	Plot 6, . . .	Extracted with water.
4	Plot 6, . . .	Extracted, and 2 tons calcium carbonate per acre.
5	Plot 6, . . .	Extracted, and 80 pounds manganese sulfate per acre.
6	Plot 6, . . .	Extracted, and 2 tons calcium carbonate and 80 pounds manganese sulfate per acre.
7	Plot 7, . . .	None.
8	Plot 7, . . .	2 tons calcium carbonate per acre.
9	Plot 7, . . .	80 pounds manganese sulfate per acre.
10	Plot 7, . . .	2 tons calcium carbonate and 80 pounds manganese sulfate per acre.
11	Plot 7, . . .	100 pounds manganese sulfate per acre.
12	Plot 7, . . .	2 tons calcium carbonate and 100 pounds manganese sulfate per acre.
13	Plot 7, . . .	150 pounds manganese sulfate per acre.
14	Plot 7, . . .	2 tons calcium carbonate and 150 pounds manganese sulfate per acre.

The seeds were planted on March 7 and 8, and began to show above the sand on the 9th, and most of them had sprouted by the 15th, when all the pots were watered for the first time. The plants came up rather unevenly, and some replanting was necessary. The replanting was done with seedlings sprouted on paraffine plates. On April 3 all the pots were thinned to 25 plants. The poorest pots at this time were Nos. 3 and 5, the extracted soil with and without the addition of manganese. All of the pots treated with manganese sulfate without lime were poorer than those receiving lime. On April 24 the above differences were even more striking. The plants on No. 5 had practically all died, while on No. 6, where calcium carbonate had been added, they made a small growth. All of the plants on the extracted soil were poorer than those on the other pots. The extraction had probably removed most of the soluble nutrients.

The clover was weighed in both the green and dry states, with the results given in Table IX. The crops were subsequently analyzed for total nitrogen, iron oxide, silica and manganese, the results of which are shown in Table X.

TABLE IX. — *Grams of Clover obtained from Pot Cultures.*

Pot.	Treatment.	Green Weight.	Dry Weight.
1	None,	8.15	1.20
2	Calcium carbonate,	22.55	3.55
3	Extracted with water,	7.00	1.05
4	Extracted, and calcium carbonate,	11.03	1.60
5	Extracted, and manganese sulfate,	5.88	.70
6	Extracted, and calcium and manganese,	17.93	2.50
7	None,	30.00	4.10
8	Calcium carbonate,	32.98	4.65
9	Manganese sulfate (80 pounds),	25.78	3.30
10	Calcium carbonate and manganese sulfate,	35.23	4.60
11	Manganese sulfate (100 pounds),	25.58	3.00
12	Calcium carbonate and manganese sulfate,	34.78	4.80
13	Manganese sulfate (150 pounds),	19.80	2.40
14	Calcium carbonate and manganese sulfate,	34.00	4.95

The soil from plot 6 was noticeably inferior in productivity to that from plot 7, when used in the pots as well as in the field. This is shown by comparing pot 1 with pot 7 and pot 2 with pot 8.

Extracting the soil with water diminished the crop, as shown in pots 3 and 4, indicating that soluble plant food was removed by the water, whether toxins were removed or not.

The addition of manganese sulfate to the soil produced a marked depression in yield on both soils when unaccompanied by calcium carbonate, while the employment of the calcium with the manganese resulted in each instance in an increase of crop beyond that produced by the calcium carbonate alone. These results are in accord with field experiments lately reported by Skinner and Reid.[1]

Chemical analysis of the clover was confined to the crops from the soil of plot 7. Manganese was found to increase in the clover tops nearly in proportion to the quantities added to the soil. The presence of calcium carbonate in the soil did not prevent the absorption of the manganese to a marked extent; therefore it would seem to have been an antidote for the poisonous effect of the manganese within the plant.

The consistent increase of the percentage of nitrogen in the crops treated with carbonate of lime is striking, and has been noted before in our field work, and reported in Bulletin No. 161.

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[1] "Action of Manganese under Acid and Neutral Soil Conditions," Bul. No. 441, U. S. Dept. Agr., 1916.

There is a singular discordance between the ill results obtained with manganese sulfate and calcium carbonate used together in water cultures and the good effects produced by their joint action in experiments with soil cultures. It is possible that in solutions the greater solubility of manganese sulfate permitted its rapid absorption by the roots in comparison with the intake of the less soluble calcium carbonate, and injurious results were produced in advance of any possible antidotal effect of the calcium.

TABLE X. — *Percentage Composition of Dry Clover from Pot Cultures.*

Pot.	TREATMENT.	Nitrogen.	Silica.	Iron Oxide.	Manganese, Parts in 1,000,000.
7	None, ...	3.04	1.03	.14	Trace.
8	Calcium carbonate, ...	3.25	1.24	.16	Trace.
9	Manganese sulfate (80 pounds), .	2.88	.71	.17	.345
10	Calcium and manganese, . . .	3.73	1.74	.24	.345
11	Manganese sulfate (100 pounds), .	3.28	1.00	.20	.640
12	Calcium and manganese, . . .	3.71	2.39	.29	.599
13	Manganese sulfate (150 pounds), .	3.15	.88	.19	1.157
14	Calcium and manganese, . . .	3.54	2.38	.26	.893

The roots were carefully washed free of soil, dried and analyzed, but the quantities were very small and determinations could not be made in duplicate in most instances; therefore the figures have not been included here.

CONCLUSIONS.

The positive presence of soluble salts of iron, aluminium and manganese in soils which have been repeatedly dressed with ammonium sulfate without adding lime; the formation of one or more of these salts in soils that were extracted with solutions of ammonium sulfate; and the positively injurious action of manganese sulfate, iron sulfate and aluminium sulfate on seedling plants in water cultures and pot cultures when taken together form a chain of facts which clearly indicates that the injurious effects of sulfate of ammonia when used freely without the accompaniment of lime are due to the formation of these soluble salts in the soils of the fields so dressed.

BULLETIN No. 177 OCTOBER, 1917

MASSACHUSETTS
AGRICULTURAL EXPERIMENT STATION

Potato Plant Lice and their Control

By W. S. REGAN

This Bulletin is a report on a serious outbreak of potato plant lice in Massachusetts during the summer of 1917, together with details of injury, identification, life cycle and natural factors influencing the destructiveness of the pest, experiments with various insecticidal materials and apparatus, and recommendations for control.

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Publication of this Document
approved by the
Supervisor of Administration.

BULLETIN No. 177.

DEPARTMENT OF ENTOMOLOGY.

POTATO PLANT LICE AND THEIR CONTROL.

BY W. S. REGAN.

ECONOMIC IMPORTANCE OF THE PEST.

Potato plants among other crops have suffered severely from the attacks of plant lice during the present summer. The extent of injury has varied considerably according to the infestation. Some potato patches with a mild infestation have shown little injury, and the loss in yield from this source will be negligible. In other fields, judging from the extent to which the tops have been killed, the crop will suffer a loss of from 10 to 50 per cent., and in some instances the destruction has been so complete that it will hardly pay to harvest the crop.

The potato plant louse (*Macrosiphum solanifolii* Ashm.) is not a new insect to this section, but conditions appear to have been ideal during the spring and early summer for its multiplication to such numbers as to cause devastation in many places where no measures were taken to check it. Nor has injury by this pest been exceptional in Massachusetts this season. Reports from Connecticut, New York, New Jersey, Maryland, Virginia and Ohio indicate that the potato crop of these States has suffered equally as much; and in some of these States, in addition to killing the potato plants in many localities, these lice were becoming dangerously abundant on tomatoes. The potato crop of Maine and Canada has also been severely curtailed during some years in the past due to these pests.

In Massachusetts injury to potato plants by plant lice became evident during the second week of July, and rapidly increased in severity until the latter part of the month and early August, when no progressive injury could be noticed, and an examination of previously badly infested fields showed these insects present only in very small numbers, and certainly not numerous enough to cause further material injury this season.

This indicates a period of about three to four weeks' time when the plant lice are dangerously prevalent upon potato plants, and reports from other sections, as well as the past history of outbreaks of this pest, indicate that this is about the length of time, dating from their first appearance in injurious numbers, when damage by these insects need be feared. During this brief period potato fields showed injury varying from little to the complete destruction of the plants. Some patches were completely free from infestation, while others near by, apparently no more attractive, were badly injured or destroyed before insecticidal treatment could be applied.

The gradual disappearance of the plant lice from the potato plants, usually about a month after infestation becomes evident, has, in many cases, been the salvation of the crop. This disappearance is due mainly to natural controlling factors, such as parasitic and predatory enemies, weather conditions and disease, all of which contribute to the destruction of myriads of these insects, and to a natural migration of the plant lice from potato plants to other host plants during the latter part of July and August. These factors will be discussed at greater length later.

Description of Potato Plant Lice.

Potato lice are yellowish or greenish in color, with an occasional pink form. Some are furnished with wings and can fly readily, while others are wingless and have to depend upon crawling for getting about. When full grown these insects are no larger than a pin head, and because of their color and small size, and the fact that they occur for the most part upon the underside of the leaves, plants may be badly infested and considerable injury result before their presence is noticed.

Manner of Feeding and Nature of Injury.

Plant lice are sucking insects and obtain their food by inserting a bristle-like beak into the host plant, from which the juices are extracted. Thus all feeding is done beneath the surface and within the tissues of the plant. On plants badly attacked the leaves begin to turn yellow, curl up, gradually turn brown and die. Under conditions favoring their growth, an attack by plant lice of a week or two will suffice to kill a large portion of the top of a potato plant, and the development of the tubers must necessarily be affected on plants thus injured. When a leaf or stem becomes too dry to afford suitable feeding ground the plant lice crawl to a fresh leaf, or migrate to other plants and continue their injury.

Where plant lice are abundant enough to cause apprehension, the underside of the leaves, stems and blossom stalks will be covered with these tiny creatures, and the plants become covered with honey dew, a sticky substance excreted by these insects. This honey dew is often attacked by a black fungus, which, together with the molted skins adhering to the sticky surface, gives the plants an unhealthy appearance and undoubtedly interferes with proper functioning.

In spite of its minuteness, the beak of the plant louse makes a wound which furnishes a suitable entrance for disease, and even if the infestation with plant lice is insufficient to injure the plants, the infection with disease thus caused may entirely ruin the crop.

LIFE CYCLE OF THE POTATO LOUSE.

Numerous observations have been made on the life cycle and habits of the potato louse (Bulletin No. 147, Maine Agricultural Experiment Station), but many important details are yet to be learned. Infestation of potato plants during the late spring and early summer is accomplished by a migration of the plant lice, either by flight or by crawling from neighboring vegetation. These new arrivals are all females, and begin at once to feed upon the sap of the plants. These females lay no eggs, but in a short time produce living offspring, which are the first of a long series of females, and these likewise in the course of eight to ten days produce living young. Plant lice are prolific breeders, a single female often producing as many as 20 young per day. It is, therefore, not astonishing that they should multiply so rapidly and cause such devastation in a comparatively short time. No males or egg-laying females ever occur upon potato plants. The first few generations may be wingless, or at any time winged individuals may appear and fly away to seek fresh plants for their own feeding and for their progeny, thus causing a more or less even infestation of potato fields.

After spending a few weeks or months upon potato plants, winged individuals called "fall migrants" appear and leave the potato plants for winter hosts, — plants of the same kind as those from which the spring migration took place to the potatoes. As previously stated, the migration to the winter hosts here in Massachusetts takes place probably to some extent during the latter part of July, but mainly during August, the exact time, however, varying according to seasonal fluctuations of temperature and moisture, and the condition of the potato plants. The early drying out or dying of the potato tops will, no doubt, hasten the appearance of "fall migrants," regardless of whether the drying out is due to injury by the plant lice or to other factors.

Observations by Miss Edith Patch, State Entomologist of Maine, seem to indicate that buckwheat and shepherd's purse are among the winter hosts sought by these insects. The migration to the winter host plants is followed by the production of winged males and wingless, egg-laying females. These females lay glistening brownish black eggs upon the leaves and stalks, and in this stage the winter is passed.

CONTROL MEASURES.

Practical Considerations and Fundamentals of Control.

Under the topic "Manner of Feeding and Nature of Injury," discussed on an earlier page, it was pointed out that plant lice obtain their food by piercing the host plant and sucking the juices from within, no feeding being done on the outer surface. Therefore any poison, such as arsenate of lead or Paris green, which is sprayed over the foliage and must be eaten in order to be effective, would be absolutely useless against plant lice, since these insects pierce beneath the poison before feeding is begun. Accordingly, a contact insecticide, a material which kills by contact with the body, is required to deal effectively with these sucking insects, and satisfactory results with an insecticide of this nature can be expected only when application is absolutely thorough. *Each insect must be hit by the spray* in order to be killed. Careless work will merely lead to a waste of material, time and energy and to a continuation of the infestation. Such carelessness, frequently due to ignorance of the essentials of application rather than intent, is often the source of complaint that material recommended for the control of plant lice is ineffective. Almost invariably unsatisfactory results with standard contact insecticides are attributable to improper application. Since potato lice confine their feeding almost wholly to the underside of the leaves, care must be taken to direct the spray upward so that the underside of each leaf will be well covered.

To apply such a spray before the infestation reaches the distinctly dangerous stage, while it might kill many of the scattered plant lice, might, on the other hand, be merely a waste of energy, for the amount of injury which the plant lice are going to inflict is purely problematical, so many elements of uncertainty enter in. For instance, weather conditions play an important part in the welfare of the plant lice. Heavy rains wash these delicate insects from the plants, and cold weather retards their increase. Warm, damp weather is favorable to a parasitic fungous disease which may destroy the plant lice over large areas. Parasitic and predatory enemies, when conditions are favorable, often destroy such numbers of the plant lice, even after considerable injury to the plants is evident, that control measures are superfluous. Then, too, the natural migration of the plant lice from potato plants to the winter hosts is an element of some uncertainty. The greater amount of injury may be completed and the plant lice soon be ready to leave the potato plants for the winter hosts before injury to the vines is extensive enough to become particularly noticeable. At this time, if the fact were known, it would hardly appeal to the average grower as an economical proposition to institute control measures.

All of these factors combine to make the matter of the desirability or necessity of artificial control measures for potato plant lice often a difficult one to determine. Furthermore, it has been the observation of the writer that in many cases where control measures have been carried out, particularly where improper application made several sprayings necessary, more actual injury was done the plants by the handling and trampling incidental to such work with a contact insecticide than, it is probable in most cases, the plant lice would have inflicted had the infestation been allowed to run its course.

One application with the proper material, properly applied to the underside of the foliage, when the infestation is severe enough to cause evident wilting of the leaves, can in most cases be made economically and to advantage, especially if injury is noticeable before the early part of

August, when the infestation is more likely to be progressive than otherwise. This is especially the case with the average garden potato patch. Over larger areas the practicability of applying treatment must be determined by the severity of the infestation, its seasonal importance, — that is, whether it is liable to be progressive or is past the dangerous stage, — accessibility, available apparatus, etc.

Reference has already been made to the fact that the winter is passed in the egg stage of the plant louse upon such plants as buckwheat, shepherd's purse and possibly various other weeds. On this account "clean culture;" the destruction by burning of potato vines, weeds and other refuse about gardens and potato fields after harvest, unless such material is composted; the burning over of grassy and weedy fields in the vicinity of potato patches in the late fall or early spring; and late fall plowing of gardens are worthy of more general practice.

The increased danger to the potato crop from "blight" after infestation with potato lice has already been pointed out. This should emphasize the need of frequent spraying with Bordeaux mixture or similar fungicide for the remainder of the growing season.

Efficiency of Various Contact Insecticides for the Control of Potato Lice.

During the early part of July, when injury by potato lice began to cause considerable apprehension, many conflicting reports were received concerning the efficiency of different contact insecticides recommended for the control of these insects. On this account, as well as from the fact that the demand at this time for nicotine sprays so exceeded the supply in many localities that it was impossible to obtain this material, it was thought desirable to have at hand some more definite knowledge concerning the effectiveness of the various common contact sprays, in order to be better able to recommend a substitute where any material desired was unobtainable.

With this end in view a badly infested potato field, already showing severe injury to the tops, due to the sucking of the plant lice, was selected to carry out these trials, which were conducted by Mr. A. I. Bourne of the Massachusetts Agricultural Experiment Station staff and the writer. All plants treated were thoroughly drenched, the under and upper sides of the foliage alike, and carefully tagged, check plants being left for comparisons. It must be kept in mind that a satisfactory contact insecticide combines safety and efficiency with reasonable cost. It must be strong enough to kill the insects and yet not injure the foliage of the plant to which it is applied, and the cost of application must not be excessive. It will be seen from the following report on these experiments that only a comparatively few dilutions of the materials tried met this test. It was impossible, in most cases, to make a very accurate estimate of the percentage of plant lice killed, so that where a percentage estimate is given it is intended to show the comparative efficiency of the various insecticides tried, and is at best only roughly approximate. It is hardly to be expected that the spraying operations of the average grower will result as successfully as those reported here, where all possible care was taken to thoroughly drench the plants.

It should be kept in mind, however, that it is only necessary to reduce the numbers of the plant lice 75 per cent. or more, when they can no longer continue an aggressive attack that will result in serious injury, but must take, figuratively speaking, a defensive position against their enemies. The parasitic and predatory enemies of the plant lice are much more resistant to contact sprays than the plant lice themselves, and in no case with the insecticides used where the plants were not injured were these beneficial insects destroyed, although they were present in numbers when application was made. The few plant lice which escape an efficient spray application fall ready prey to these enemies. A report of the results of these tests follows: —

MATERIAL AND DILUTION.	Plant Lice killed.	Injury to Plants.
"Black Leaf 40" (1–400) with soap,	99–100 per cent.,	No injury.
"Black Leaf 40" (1–800) with soap,	98–99 per cent.,	No injury.
"Black Leaf 40" (1–800) with Pyrox, no soap.	98 per cent.,	No injury.
"Black Leaf 40" (1–1,000) with soap,	Not over 75 per cent.,	No injury.
"Black Leaf 40" (1–1,600) with soap,	Ineffective, few killed,	No injury.
"Nico-Fume" liquid (1–750) with soap,	98 per cent.,	No injury.
Fish-oil soap (1–5),	98–99 per cent.,	No injury ?
Fish-oil soap (1–6),	98 per cent.,	No injury.
Fish-oil soap (1–8),	Not over 50 per cent.,	No injury.
Kerosene emulsion (1–9),	90 per cent.,	No injury.
Miscible or soluble oil (1–25),	Perfect kill,	Plants killed.
Miscible or soluble oil (1–40),	Perfect kill,	Considerable injury.
Miscible or soluble oil (1–50),	98–99 per cent.,	Some injury.
Miscible or soluble oil (1–64),	98 per cent.,	Some injury.
Lime-sulfur, 34° Beaumé (1–22),	Ineffective, not over 20 per cent.,	Some injury.
Lime-sulfur, 34° Beaumé (1–43),	Ineffective,	No injury.

Discussion of Results.

1. *"Black Leaf 40."* — This material is perhaps the insecticide most commonly used for the control of plant lice, but any of the other nicotine preparations of a similar nature now on the market should give satisfactory results. It is a concentrated solution of nicotine sulfate, containing 40 per cent. of nicotine by weight. It was tried with four dilutions — 1–400, 1–800, 1–1,000, and 1–1,600 — in each case, with the addition of soap at the rate of 2 pounds to 50 gallons of the diluted "Black Leaf 40." Both ordinary hard laundry soap and liquid soap were used with similar

results, the hard soap being cut into small pieces and dissolved in boiling water before adding to the solution. If liquid soap is used, 1 quart should be added to every 50 gallons of the diluted "Black Leaf 40." In addition to increasing the effectiveness of this nicotine preparation the soap aids materially as a spreader, thus insuring a more uniform coating of the foliage and a more perfect "hit" of the plant lice.

All of the four dilutions tried showed no foliage injury, but only the 1–800 strength met the test of reasonable economy and efficiency. This strength showed nearly a perfect kill.

The dilution 1–800 reduced to practical terms is as follows: —

"Black Leaf 40,"	½ pint.
Hard soap, dissolved in boiling water,	2 pounds (liquid soap, 1 quart).
Water,	50 gallons.

Reduction to a small amount would be as follows: —

"Black Leaf 40,"	1¼ teaspoonfuls.
Hard soap, dissolved in boiling water,	⅔ ounce.
Water,	1 gallon.

The cost of this spray material will depend mainly upon the quantity of the "Black Leaf 40," or similar nicotine preparation, purchased. In an amount of 10 pounds, which diluted as recommended (1–800) would give 1,000 gallons of spray mixture, the cost amounts to but little over 1 cent per gallon. If purchased in an amount as small as an ounce the cost is increased to something over 4 cents a gallon.

2. *"Black Leaf 40" and Pyrox, etc.* — The question has frequently been asked as to whether or not "Black Leaf 40" can be safely combined with Pyrox, Bordo-lead and other materials, such as arsenate of lead and Bordeaux mixture, thus reducing the labor involved in making separate applications. Pyrox and Bordo-lead are a combination of an arsenical and a fungicide, and are used for the control of leaf-eating insects, such as the potato beetle, and fungous diseases. "Black Leaf 40" and Pyrox or Bordo-lead can be safely combined with equally as good results as when these materials are used separately. However, *soap should not be used* with such a combination, and should never be used in any combination containing Pyrox, Bordo-lead or Bordeaux mixture, as an "incompatible mixture" results. "Black Leaf 40," or any similar nicotine preparation, may also be safely combined with arsenate of lead or Bordeaux mixture, — but without the addition of soap.

3. *"Nico-Fume" Liquid.* — This material is somewhat similar to "Black Leaf 40," being a nicotine preparation containing 40 per cent. free nicotine. There appears to be little or no difference in the effectiveness of these two materials, and since the "Nico-Fume" liquid is the more expensive, it is suggested merely as a possible substitute in case the "Black Leaf 40" is not obtainable. It was used at approximately the same strength as the "Black Leaf 40," and with the addition of a like

amount of soap. Combinations of "Nico-Fume" liquid with other insecticides and fungicides can be made with the same restrictions as for "Black Leaf 40."

4. *Fish-oil or Whale-oil Soaps.* — These soaps have long been used for the control of plant lice. Three dilutions were tried, — 1 pound to 5 gallons of water, 1 pound to 6 gallons of water, and 1 pound to 8 gallons, the soap being cut up into small pieces, dissolved in boiling water, and diluted with cold water to the required strength. The 1–5 and 1–6 strengths showed high efficiency. The 1–8 strength was unsatisfactory, not more than half of the plant lice being killed. There was some suspicion of foliage injury at the 1–5 strength, but this was not extensive, and, since some of the tops had been killed by the plant lice, this point could not be definitely determined. The 1–6 strength proved efficient and showed no injury. Used at this strength the cost of fish-oil or whale-oil soap spray is approximately that of the "Black Leaf 40" solution, 1–800; that is, less than 2 cents per gallon where a quantity of the soap to the amount of 5 pounds or more is purchased. Since the amount of soap to be dissolved in case the fish-oil or whale-oil soap is used is greater than the quantity used with the "Black Leaf 40" solution, the latter is perhaps somewhat preferable because of the smaller outlay of time and bother thus involved. These soaps, however, furnish an excellent substitute in case of difficulty in obtaining the nicotine preparation. Pyrox, Bordo-lead, Bordeaux mixture or similar materials should never be used with soap of any kind.

5. *Kerosene Emulsion.* — This material was made according to the usual stock formula, as follows: —

Hard soap,	½ pound (liquid soap, ½ pint).
Water,	1 gallon.
Kerosene,	2 gallons.

The soap is cut into small pieces and dissolved in the water, which should be boiling. The soap solution is then poured into the kerosene while hot, and churned back and forth with a spray pump until a creamy mass is formed and no free oil is present. This can usually be done satisfactorily in from ten to fifteen minutes. The emulsion formed is a stock solution, which should be diluted at the rate of 1 part to 9 parts of water for plant lice.

It was supposed that kerosene emulsion, a standard remedy for plant lice and other soft-bodied insects, would prove highly effective against potato lice, but the trials with this material proved disappointing, as not more than 90 per cent. of the insects were killed. This indicates an efficiency for kerosene emulsion considerably less than that of the "Black Leaf 40," 1–800, and the fish-oil soap, 1–6. Furthermore, the trouble and time involved in making the emulsion, as well as the danger of foliage injury when this material is improperly made, militate against its use where the other materials referred to above are obtainable. The cost of the kerosene emulsion per gallon of the diluted spray is something over 1 cent, or approximately the same as for the "Black Leaf 40" and the fish-oil soap solutions.

6. *Miscible or Soluble Oils.* — One of the standard commercial brands of miscible oils was used in these tests, this being tried with four dilutions, — 1–25, 1–40, 1–50 and 1–64. This material in all four dilutions showed a very high killing efficiency, but even at the greatest dilution, 1–64, showed distinct oil injury to the potato foliage. In justice to this material, however, it must be said that the sample experimented with was not perfect, as there was some free oil evident, an ever-present danger, nevertheless, with this material. Time did not permit obtaining a fresh sample of miscible oil, so that this material must be placed in the questionably dangerous class until further experiments prove to the contrary. The cost of this material is less than that of any of the other insecticides referred to, and obtained in any quantity would amount to less than 1 cent per gallon of diluted spray material.

7. *Lime-sulfur.* — A standard commercial brand of this material, having a density of 34 Beaumé, was used in these tests. Two dilutions were tried, — 1–22, which is about twice the normal strength for application to foliage, and 1–43, which is about the usual dilution for foliage spraying. Even at the 1–22 strength this material killed only a comparatively small number of plant lice, and could in no way be considered an effective aphidicide. Furthermore, at this strength there was evident foliage injury shortly after application, which took the form of a wilting or drooping of the plants. The next day, however, the plants thus injured seemed to have entirely recovered.

Spraying Apparatus.

Satisfactory spraying outfits for applying insecticides are equally as important as efficient spray materials. Ordinary hand atomizers are useless, since it would be necessary to turn over every plant so that the underside of the leaves could be reached. Such handling would probably result in as much injury to the plants as the plant lice would be likely to inflict. For small garden potato patches, perhaps up to a quarter of an acre, a knapsack or compressed-air spray pump will prove satisfactory. These pumps hold from 3 to 5 gallons of spray, but the frequent need of refilling makes them less desirable for use where larger areas are to be treated. In spraying operations involving fairly large potato fields a barrel pump, traction outfit, power sprayer or similar apparatus will be found the only practicable thing.

Regardless of the type of pump used, an extension rod and an underspray nozzle at a right angle to the rod are essential in order that the underside of the leaves may be easily reached. For a knapsack or compressed-air pump a 3 or 4 foot extension rod of iron or brass is perhaps most convenient. A 4 or 5 foot length of iron pipe is, perhaps, most satisfactory when directing the spray by hand from a barrel pump, power sprayer or similar apparatus, but numerous combinations of rods and nozzles may be made to increase the spraying area or the number of rows treated at one time. In the case of traction sprayers or other direct row-spraying apparatus the common inverted T method is ordinarily used with two nozzles attached to throw spray in opposite directions, so that two rows may be treated from each T. By attaching several T's to the main cross rod, so that the T's come between the rows, a number of rows may be sprayed simultaneously. It is essential with such apparatus that the T's be made sufficiently long and the nozzles attached at the proper angle to thoroughly drench the underside of the foliage. Work with such apparatus must be done slowly if satisfactory results are to be expected. Some growers have adopted an arrangement with traction sprayers whereby a cross piece, located a short distance in front of the nozzles, tips over the plants. The nozzles are directed forward and downward so that, theoretically, while the plants are thus tipped over, the underside of the leaves are covered with the spray. Not only is the efficiency of this method open to doubt, but the effect upon the plants of such treatment is worthy of consideration.

A nozzle giving a fine mist spray is essential. The disk and Vermorel are two types of nozzles well adapted for the work. The disk nozzle must be of the *angle form*, which gives a suitable underspray at a right angle to the rod, and covers a fairly large area, being on this account preferable to the Vermorel nozzle. The Vermorel nozzle cannot be purchased in the angle form, but a 45° elbow can be obtained or a bend made in the extension rod to overcome this difficulty. It is fairly well adapted for use with a knapsack or compressed-air pump.

Where a considerable length of hose is needed it is desirable to have this as light as possible in order to facilitate handling among the rows with the least possible injury to the plants. One-fourth inch Meruco tubing has been found highly satisfactory for this purpose, especially for the leading hose. Attachments for this tubing to rubber or cotton hose of larger size can be readily obtained. Long-tail hose couplings will also be found advantageous in preventing a "blow-out" where pressure of any amount is used.

Summary of Control Measures.

1. Potato plant lice can be readily controlled by the use of a contact insecticide of "Black Leaf 40" or similar nicotine preparation at the rate of 1 part of this material to 800 parts water, with the addition of common laundry soap, dissolved in boiling water, at the rate of 2 pounds (liquid or soft soap, 1 quart) to 50 gallons of the diluted "Black Leaf 40" solution. The formula in practical terms is given on an earlier page.

Fish-oil or whale-oil soap at the rate of 1 pound to 6 gallons of water is about equally as effective, but is less desirable on account of the extra time and bother involved in dissolving larger quantities of soap.

"Black Leaf 40" can be combined safely with Pyrox, Bordo-lead, Bordeaux mixture or arsenate of lead, but soap should be omitted when such combinations are made. These combinations are equally as effective as when the materials are used separately.

Kerosene emulsion is not highly effective against potato plant lice, and the labor involved in preparing this material is also against its use.

Tests with miscible or soluble oils seem to indicate that these materials are dangerous to use upon potato foliage.

Lime-sulfur is ineffective for the control of potato plant lice even at double the ordinary strength used upon foliage.

2. Satisfactory results with an efficient contact spray can be expected only when thorough work is done. *Each insect must be hit with the spray.* Since plant lice confine their work almost wholly to the underside of the leaves, the spray must be directed upward from underneath the plants. An *angle disk* nozzle or similar underspray nozzle is necessary for such work. One thorough application with an efficient spray should control potato plant lice so that a second treatment will be unnecessary. Too much handling or trampling about the plants will often result in more injury than the plant lice are likely to cause.

3. The practicability of applying treatment for the control of potato lice, especially over large areas, must be determined by the severity of infestation, its seasonal importance, — that is, whether it is likely to be progressive or is diminishing in severity, — accessibility, available apparatus, etc. If injury to the plants has not been severe enough to kill portions of the tops of the plants to an evident extent before the 1st of August, it is probable that the injury likely to be done will not exceed the cost of applying treatment. When severe injury is noticeable before the 1st of August, a thorough treatment should be made *at once.* Application before the insects are present in numbers will be merely a waste of time and energy.

4. The destruction by burning of potato vines after harvest, together with all weeds and other refuse about gardens and potato fields, unless such material is composted; the burning over of grassy and weedy fields in the vicinity of potato patches in the late fall or early spring; and late fall plowing of gardens are methods of clean culture which may materially reduce future infestation.

5. Injury by potato lice renders the plants more susceptible to "blight," and should emphasize the need for frequent sprays with Bordeaux mixture.

Natural Agents in the Control of Potato Plant Lice.

Many factors contribute to a natural control of potato lice; in fact, to such an extent that during most seasons in the past their injury has been unimportant in Massachusetts.

Weather conditions rank very high among controlling influences. Cool or wet weather offers quite a decided check to aphid development, and heavy or continuous rains undoubtedly destroy many of these delicate insects.

Among the predatory enemies of plant lice, lady beetles and their young, and the larvæ of syrphus flies, are most important. Both as adults and during the immature stages, lady beetles are voracious feeders upon plant lice as well as upon other tiny insects. The average person readily recognizes a lady beetle and knows its beneficial habits, but the lady beetle young, being of an entirely different appearance, are often mistaken for injurious forms and unfortunately are destroyed. These young vary in length all the way up to about a half inch, are bluish or blackish in color, often with orange spots on the back, and resemble very much a miniature alligator in general appearance. They crawl about freely, destroying large numbers of the plant lice. The syrphus fly young are maggot-like forms, being pointed at the head end and somewhat broader behind, and are of variable length but average about one-fourth of an inch. These are ordinarily orange, greenish or whitish in color, are very sluggish, but destroy, nevertheless, numbers of the plant lice.

Tiny, almost microscopic, wasp-like insects also aid in the destruction of plant lice, their young living parasitically in the bodies of these pests.

During certain seasons, especially when there is an abundance of warmth and moisture, a fungous parasite attacks these plant lice and destroys large numbers. In some localities this disease has been credited with having practically exterminated the plant lice after they had become numerous enough to menace seriously the potato crop.

ACKNOWLEDGMENTS.

The foregoing is not presented as a "distinct contribution to scientific knowledge," but is merely an attempt to present in available form facts already determined by others, together with results of personal observations and experience.

The writer wishes to acknowledge credit to Bulletin No. 147, Maine Agricultural Experiment Station, for certain facts and suggestions made use of in this paper; and is indebted to Mr. A. I. Bourne of the Massachusetts Agricultural Experiment Station staff for assistance in carrying out the insecticide tests.

The work has been carried out under the direct supervision of Dr. H. T. Fernald, whose kind co-operation has been of much help.

BULLETIN No. 178 DECEMBER, 1917

MASSACHUSETTS
AGRICULTURAL EXPERIMENT STATION

THE EUROPEAN CORN BORER

PYRAUSTA NUBILALIS HÜBNER

A RECENTLY ESTABLISHED PEST IN MASSACHUSETTS

By S. C. VINAL

This Bulletin reports the discovery of the fact that the European corn borer, *Pyrausta nubilalis* Hübner, has gained a foothold in Massachusetts; gives a brief account of its life history and habits; and suggests methods of control and the probable necessity of action by the State or Federal governments.

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[1] On leave.

[2] On leave on account of military service.

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Publication of this Document
approved by the
Supervisor of Administration.

BULLETIN No. 178.

DEPARTMENT OF ENTOMOLOGY.

THE EUROPEAN CORN BORER,

Pyrausta nubilalis Hübner,

A RECENTLY ESTABLISHED PEST IN MASSACHUSETTS.

BY S. C. VINAL.

Nearly every year we find a new insect pest of foreign origin has become established in some section of the United States. To the long list of European pests now found in Massachusetts this article adds one more, — the European corn borer or corn pyralid, *Pyrausta nubilalis* Hübner, recently established in the vicinity of Boston, Mass. This species has long been recorded as one of the most serious enemies to maize culture in Europe, and if not checked may in time become a very serious pest to America's great corn crop.

Discovery and Identification.

During the past summer the writer found many corn plants in the vicinity of Boston, Mass., being tunneled by light colored caterpillars, the identity of which was unknown. During July nearly every infested plant could be readily detected, having its tassel broken over and hanging pendent just above the first two or three spikes. This was due to the larval tunnels in the pith of the main tassel stalk so weakening it that the wind readily blew it over.

Early in August moths emerged from pupæ collected in the field, and having Dr. C. H. Fernald's collection of both native and exotic moths available, a successful attempt was made to determine the species. Specimens of both male and female pyralid moths which corresponded identically to those obtained from infested corn stalks in eastern Massachusetts were found in his European collection. These were determined by M. Ragonet, a French lepidopterist, and were labeled *Pyrausta* (Botys) *nubilalis* Hübner. Further proof of the identity of this moth was obtained by submitting specimens to Mr. H. G. Dyar of the United States National Museum, Washington, D. C., who determined them to be *Pyrausta nubilalis* Hübner, a native of Europe.

Description of the Insect.

When full grown the larva is 1 inch in length; the body is flesh-colored, often somewhat smoky or reddish above, while the head is flat and dark brown in color. On close observation a transverse row of four light colored spots, with two smaller ones immediately behind them, can be seen on each abdominal segment. From each of these light colored areas a short, stout spine arises, and this character distinguishes the European corn borer from the mature caterpillar of the potato and corn stalk borer (*Papaipema nitella* Gn.).

The female moth has a robust body, is pale yellow in color and has a wing expanse of a little over 1 inch. The outer third of the fore wing is traversed by two serrated lines darker than the rest of the wing, while the hind wings are light yellow in color.

The male moth has a long, slender body, is slightly smaller in wing expanse, and in color is reddish brown, being much darker than the female. Between the two serrated lines mentioned above is a pale yellow streak, and near the middle of the fore wing are two small yellowish spots. The hind wings are grayish and crossed by a broad band of pale yellow.

European History.

Pyrausta nubilalis is widely distributed in Europe and Asia, having been reported in literature as occurring in Central and Southern Europe, West Central and Northern Asia and Japan. Its food plants in these widely separated localities consist of corn (except fodder corn), hemp, hops, millet and several wild grasses. Corn and hop plants are severely damaged by this pest, 50 per cent. of these crops being destroyed in some sections of Central Europe.

Foreign literature contains a large number of references to the serious damage caused by the larvæ of *P. nubilalis*, but there is a decided lack of literature dealing with its biology and control.

Status of the Pest in Eastern Massachusetts.

Importation.

The questions naturally arise as to how, when and where the European corn borer was introduced. At the present time these cannot be definitely answered, but a few deductive conjectures may be given.

The important European food plants of *P. nubilalis* consist of corn, hemp, hops and millet. Of these the only food plant offering ideal conditions for its importation is hemp. This crop is grown to some extent in Southern Europe, and probably some plants infested by larvæ of *P. nubilalis* were cut and shipped during the fall and winter months to a cordage company in the vicinity of Boston, Mass. These plants were not used immediately, and the larvæ transformed to pupæ in early spring, and soon emerged as moths. On finding corn plants growing in the vicinity, oviposition took place and the European corn borer became established.

Early sweet corn grown in market gardens 10 to 12 miles inland has been seriously attacked by this pest for the past three or four years, and from this we might infer that it was imported about 1910.

A survey of eastern Massachusetts showed that some towns located at the mouth of the Mystic River were more generally infested than others. At the mouth of this river is located the Charlestown Navy Yard, which probably has one of the largest "rope walks" in Eastern United States. Whether the European corn borer was first introduced at the Navy Yard, or at some cordage company located on the opposite bank of the river, it has been impossible to ascertain, but enough has been written to show that it probably was first established in this vicinity.

Present Distribvtion.

The area infested by the European corn borer in Massachusetts is approximately 100 square miles in extent, and is located immediately north and northwest of the city of Boston. The places most severely infested during the past season were Somerville, Medford, Malden, Everett, Chelsea, Revere, Lynn, Saugus, Melrose, Stoneham, Winchester, Arlington, Belmont, Cambridge, Brookline and the following parts of Boston: South Boston, Brighton, Roxbury and Dorchester.

Food Plants.

At the present time sweet corn is the only valuable commercial crop seriously attacked by this pest, for the other food plants — hops, hemp and millet — are not grown within the infested region of Massachusetts. The most commonly infested weeds and grasses are barnyard grass (*Echinochloa crus-galli* Beauv.), pigweed (*Amaranthus retroflexus* L.) and foxtail grass (*Setaria glauca* Beauv.). Dahlia stems are also injured by the European corn borer. The moths apparently prefer to oviposit on corn, and will not infest weeds and grasses unless corn plants are not available in sufficient numbers.

Importance.

Sweet corn is practically the only corn grown within the infested area, and the amount of damage caused by the European corn borer depends upon whether it is an early or late variety. The early crop of sweet corn is picked during late July and early August, and by reference to the life history it will be seen that these plants are subjected to the attack of the first brood of larvæ only. The late corn, however, suffers from the attack of both the first and second broods of larvæ. While the early crop may be damaged to the extent of 10 to 20 per cent., the loss to late corn plantings may be as high as 75 to 80 per cent. This higher percentage of damage to late corn is caused by the habit of the small second brood larvæ of boring through the husk and tunneling in the developing ear, making it worthless for market.

CHARACTER OF INJURY.

With the exception of the leaf blades the whole corn plant above ground is subject to the attacks of these voracious caterpillars.

The larvæ after emerging from the egg either commence feeding on the unopened staminate flowers borne by the tassel, or immediately pierce the sheath near its junction with a node. Those which feed on the tassel bore a hole in the side of the buds and feed on the internal succulent parts. Soon these small caterpillars leave the tassel buds and enter the tassel stalks, or terminal internode, where they tunnel through the pith and finally complete their larval life in this internode. These tunnels so weaken the terminal internode that it soon becomes broken over, a type of injury which is especially noticeable on the early corn crop. It is quite evident that this injury indirectly affects the formation of corn on the cob by destroying the pollen necessary for fertilizing the corn silk.

Those larvæ which do not feed on the tassel immediately pierce the sheath surrounding an internode, usually where the edges overlap at its junction with a node. Here they feed on the internal surface of the sheath, excavating a groove halfway around the stalk, and then bore directly into the pith where they form long winding tunnels. Whenever the larvæ during their tunneling operations reach a node, a rather large cavity is usually formed. From this cavity the larvæ sometimes bore through the node, but more often they turn and tunnel in the opposite direction in the originally infested internode. At the termination of the feeding period nearly all of the central portion of the stalk has been eaten, and this so weakens the plant that a strong wind is likely to break over the stalk, thus completing the destruction commenced by the caterpillars.

A number of these stalk-boring larvæ very often attack the small stalk or pedicel bearing the ear, and in some cases may bore directly through this into the developing ear. This injury to the pedicel causes the ear to wither and die.

The most serious damage to the crop is caused by the large percentage of the second brood larvæ which immediately enter the ear after hatching. The injury by this brood to the corn ear is very similar to that caused by the well-known corn ear worm (*Chloridea obsoleta* Fab.). Besides feeding on the kernels in a similar manner to the corn ear worm, the European corn borer exhibits characteristic tunneling habits and bores through the cob.

LIFE HISTORY AND HABITS.

As the life history has not been thoroughly worked out, it is only possible to give a brief résumé of it at the present time.

There are two broods a year of the European corn borer. Hibernation takes place as full grown or nearly full grown larvæ, within their tunnels in the corn stalks, and in some cases in the cob. These larvæ pupate in the spring and emerge as moths, probably the latter part of May. Soon after emergence the females begin laying eggs on the corn stalks, and in a few days these hatch. The young larvæ begin feeding at once, and quickly eat their way through the sheath before they tunnel in the main stalk.

On reaching maturity, which occurs the latter part of July, the larvæ clear out a portion of the burrow, prepare an opening through which the adults can escape, and after spinning a thin silken partition across the top and bottom of this cleared space, transform to pupæ. The moths emerge for the second brood in about two weeks. This brood of larvæ becomes full grown by late fall, but does not transform to pupæ at once as in the first brood. Instead, the winter is passed as larvæ within the stalks, pupation taking place the following spring.

Control.

From the brief sketch of the life history it is apparent that there is no hope of destroying this pest during the summer by the use of insecticides, since all of its transformations take place *within* the plant. Our main hope lies in the possibility of establishing a system of cultural methods which will enable us to *prevent* injury. The fact that the winter stage is passed in the food plant suggests control measures which should result in killing the great majority of the hibernating insects. These measures, if carefully followed, should reduce the injury of the following season materially.

1. *Burning the Stalks during the Fall or Winter.* — While this is undoubtedly one of the most effective measures for the destruction of the hibernating insects which can be adopted, it is somewhat wasteful, for the stalks are valuable either for feed or as a source of humus so necessary for maintenance of fertility and texture in the garden soil. Burning, therefore, is inadvisable when other effective methods can be used.

2. *Burying the Stalks.* — In home gardens the stalks may be put in trenches and covered by at least 1 foot of soil. In larger market gardens the stalks may be placed in the center of manure piles until decomposed. In some cases plowing under might be resorted to, but the work must be thorough or it will be ineffective. Any stalks left on the surface are likely to harbor a crop of borers for the next season. If corn stalks are distributed over the land and then cut up by running a disk harrow over the field in both directions it should be possible to turn them practically all under.

It should be clearly understood that half-hearted work is of little value. Occasional stalks which it may seem hardly worth the trouble to clean up are likely to harbor enough borers to severely infest the spring crop.

3. *Feeding the Stalks.* — From the economic point of view this is the best possible means of destroying the hibernating insects, since the value of the stalks for fodder is not materially affected by the presence of the insects, and if properly carried out this method must result in the destruction of practically all of them. Feeding the stalks whole will be relatively ineffective, since parts not eaten by the animals are likely to harbor insects. Shredding the stalks, whether to be fed green or dry, must greatly

reduce the chances that any of the insects will survive. Ensilage by ordinary methods must prove a highly effective method of destroying the insects present in the stems or other parts of the affected plants, for it would seem to be in the last degree improbable that they could survive under the conditions existing in the silo.

Co-operation.

It has been pointed out that the caterpillars which survive the winter emerge as moths which fly freely the following spring. Consideration of this fact makes it apparent that no method of control can be even fairly satisfactory unless all those cultivating corn in an infested district co-operate to insure as far as may be possible the destruction of all hibernating insects. A few neglected gardens in any vicinity may harbor enough borers to infest a wide area.

Measures for insuring or compelling satisfactory handling of all infested material are, therefore, very necessary, and, while the desired end might possibly be obtained by local organizations of farmers and gardeners and vigorous action, it seems probable that the matter must be taken in hand by the State or Federal government if the insect is to be brought under control.

BULLETIN No. 179 NOVEMBER, 1917

MASSACHUSETTS AGRICULTURAL EXPERIMENT STATION

The Greenhouse Red Spider attacking Cucumbers and Methods for its Control

By STUART C. VINAL

This Bulletin deals primarily with the development and discovery of an efficient control for the common red spider attacking cucumbers grown under glass; and secondarily with the more biological phases, including distribution, importance, life history and habits of this pest under greenhouse conditions.

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Publication of this Document
approved by the
Supervisor of Administration.

BULLETIN No. 179.

DEPARTMENT OF ENTOMOLOGY.

THE GREENHOUSE RED SPIDER ATTACKING CUCUMBERS AND METHODS FOR ITS CONTROL.

(*Tetranychus bimaculatus* Harvey.) (Class, *Arachnida;* Order, *Acarina;* Family, *Tetranychidæ.*)

BY STUART C. VINAL.

INTRODUCTION.

The minute spinning mites, commonly called red spiders, have long been known as among the most troublesome of greenhouse pests, although they also cause a great deal of damage to flowers, vegetables and trees growing out of doors. A greenhouse affords an almost ideal environment for the development and rapid multiplication of red spiders, and as a consequence we find this pest taking advantage of the opportunity offered and doing great damage to many of the principal crops grown in greenhouses.

The production of vegetables under glass is an expensive process, involving a large investment of capital and a continual expense to maintain such an establishment. To counterbalance this expense the value of the crop must be proportionally high, and anything which interferes with the fullest development of the plants reduces the profits materially.

Without doubt the common red spider (*Tetranychus bimaculatus* Harvey) is the most widely distributed and destructive pest of greenhouse cucumbers. Nowhere in America is the cucumber forcing industry more highly developed than in the market-garden district of Boston, Mass., and therefore the injury caused by this pest assumes its greatest economic importance in this section.

During the last few years numerous inquiries have been received by the Massachusetts Experiment Station from market gardeners in regard to the control of red spiders attacking greenhouse cucumbers. Because of the lack of an efficient method of control very few recommendations could be given, and in many cases the injury by these mites resulted in serious losses. Thus it soon became evident that some line of investigation should be conducted on the control of this mite attacking greenhouse crops, and in October, 1915, this problem was assigned to me.

The investigations upon which this paper is based were carried on under the direct supervision of Dr. H. T. Fernald. The thanks of the writer are due Dr. H. T. Fernald, Dr. G. C. Crampton and Dr. W. S. Regan for their interest throughout the progress of the work. Acknowledgments are also due the chemistry department of the station for its co-operation, expecially to Dr. E. B. Holland for his interest and careful manufacture of many complicated spray materials which led to the discovery of an efficient control for the greenhouse red spider. The writer is also under obligations to Mr. H. F. Tompson, professor of market gardening, for suggesting this research and for much valuable information concerning the efficiency of control measures when used in commercial houses. To Mr. M. E. Moore of Arlington and Mr. J. Winthrop Stone of Watertown the writer gratefully acknowledges his indebtedness for their kind co-operation in allowing promising materials to be thoroughly tested on a commercial scale in their greenhouses.

As this paper has to deal primarily with the control of the greenhouse red spider, other more biological phases will be discussed only briefly, unless they have a direct bearing upon control measures.

HISTORY AND DISTRIBUTION.

The greenhouse red spider of New England was first described by Harvey in 1893 as *Tetranychus bimaculatus*. He considered it distinct from the European species *Tetranychus telarius* Linn., and later workers have failed to prove conclusively the identity of these species.

The first account of serious injury caused by this mite in the United States came from the New England States, where it caused much damage to greenhouse plants. In 1855 a mite, since described by Banks as *T. gloveri*, but now known as *T. bimaculatus* Harvey, was reported by Glover as doing injury to the cotton plants of the south. This injury increased in importance, and in 1900 the Bureau of Entomology, United States Department of Agriculture, established a southern laboratory to work on the control of this pest. With the development of greenhouses in the west the ravages of the red spider scon appeared and caused serious damage to greenhouse plants as well as to many cultivated garden plants and fruit trees. A closely related mite has long been a serious pest of hop plants in Europe; therefore it is not surprising that our species of red spider assumes a great importance in seriously damaging hop fields both in the east and far west.

The red spider, therefore, is very generally distributed throughout the United States, extending from Maine to Florida and westward to Texas and California, only a few States in the western arid region being exempt from the ravages of this pest.

FOOD PLANTS.

Tetranychus bimaculatus is very cosmopolitan in its feeding habits, having been listed by McGregor as feeding on 183 species of plants, 55 per cent. of which were cultivated, in the southeastern part of the United States. Much confusion has arisen because of the large number of host plants and the variability in color of mites feeding on these different plants. New species have been described based upon these color variations, but they have been discarded by later workers as synonymous.

Under New England conditions of climate the red spider as a rule does not seriously damage plants except those which are usually grown in greenhouses. A few exceptions to this statement may occur near badly infested greenhouses or during very dry seasons. As this paper has to deal with greenhouse control, only those plants found most often infested in, and in the vicinity of, greenhouses will be enumerated.

The greenhouse vegetables most subject to attack are (1) cucumbers, (2) egg plants and (3) tomatoes.

Cucumbers grown under glass in the market-garden district of Boston are rarely exempt from the attacks of red spiders. These plants are first attacked when only two leaves have unfolded, and injury continues until the death of the plant, which in the majority of cases is due primarily to the removal of chlorophyll from its leaves by the mites. Egg plants, although very susceptible to attack, are not generally grown in the vicinity of Boston. Greenhouse tomatoes appear to be practically immune from red spider injury except when very young. Several times the writer has seen a greenhouse containing approximately 1,500 full-grown cucumber plants, with a row of tomatoes planted at each end of the house. The cucumber plants were rapidly dying from the injuries caused by millions of red spiders, while the tomatoes remained unaffected. This was an extremely severe infestation, and shows to what extent greenhouse tomatoes are immune. Almost all weeds found in infested greenhouses harbor mites, and if not destroyed are liable to infect a following crop.

The greenhouse flowers subject to attack are (1) roses, (2) violets, (3) sweet peas, (4) carnations, (5) chrysanthemums and (6) many others of minor importance.

In floriculture perhaps the most important infestations occur on roses and violets, with sweet peas, carnations and chrysanthemums next in order. Usually a very large number of widely differing plants are grown in a florist's greenhouse, and many of these will become more or less seriously infested by the migration of mites from one or more of the above-mentioned plants. However, these infestations are usually not of great importance.

The plants in the vicinity of greenhouses subject to attack are (1) beans, (2) egg plants, (3) celery, (4) tomatoes, (5) strawberries, (6) clover, (7) grasses and (8) weeds.

Plants subject to attack which are found near greenhouses may serve as sources of inside infestation, or may in turn become infested from plants or parts of plants thrown out of the greenhouse during or after an infestation. The most important garden crops attacked are the bean, egg plant and celery. Tomatoes grown out of doors are more susceptible to red spider injury than when grown in greenhouses. Strawberry plants are also subject to attack, but usually this does not assume great importance under New England climatic conditions. The most important plants, as far as the greenhouse man is concerned, are those found around most greenhouses, consisting of clover, grasses and weeds, as these are undoubtedly important factors in causing inside infestation.

NATURE OF INJURY TO CUCUMBERS.

The first signs of injury appear soon after the plants have been transplanted in the greenhouse, and in the majority of cases on the oldest, basal leaves. The pests usually attack the leaves of a cucumber plant progressively; that is, the older, basal leaves first show injury, then those just above are attacked, and thus the ravages of the pest progress upward as the plant grows. As a general rule very young, hairy leaves around the terminal shoot are exempt from attack until the plant becomes very heavily infested.

The injury is caused by the puncturing of the under surface of the leaf and the extraction of the liquid contents of the leaf cells immediately surrounding the puncture, which results in a very characteristic and noticeable injury. In the process of feeding, the green chlorophyll is withdrawn, leaving a small dead area which soon appears on the upper surface of the leaf as a small whitish speck. As the mites continue feeding, the removal of chlorophyll and specking increases until ultimately the leaf becomes yellowish, lifeless and useless for food assimilation.

The characteristic red spider injury is quite easily recognized, even in its early stages of development. The normal leaf is opaque, allowing no light to pass through it, while around injured areas considerable light passes through the leaf tissue, due to the lack of chlorophyll in this vicinity. The contrast between the opaque normal leaf tissue and the lightness seen around affected areas is especially noticeable when the cucumber plants have become full-grown and have leaves and terminal shoots running over the top wires, for at this time the leaves are between the source of light and the observer walking beneath them. The appearance on the upper surface of the minute, pitted dead specks or spots, usually arranged in clusters, will also point to infested areas.

ECONOMIC IMPORTANCE OF THE PEST ON CUCUMBERS.

The damage caused by red spiders in cucumber houses varies in severity. The factors influencing this have not been determined, but at least they are very complicated. The severest injury seems to occur in houses containing a light sandy soil, while houses having heavy soils are better able to withstand the attacks of this pest. Nearly every cucumber grower in the Boston district, so far as the writer has been able to determine, is forced to fight red spiders in order to bring his crop to maturity. In many cases whole houses of young cucumber plants have been destroyed with sulfur fumes because the mites were so numerous and the injuries so severe that it was deemed wise by the grower to destroy the plants and reset the house. The usual methods used by greenhouse men to combat this pest consist of severe pruning of infested plants and spraying with as strong a stream of water as these delicate plants will stand, repeating this as often as possible without allowing mildew to seriously injure the leaves. In nearly all cases the mites win out in the struggle for existence, and shorten the life of a cucumber plant over one month. Under normal conditions the plant should bear a large amount of fruit during this time. The loss, therefore, to cucumber men by red spider infestation is due to shortening the life of the plant during its productive period.

A conservative estimate of the value of the cucumber crop grown within the market-garden district of Boston is $1,500,000 per season. The cucumber growers suffer a loss of approximately $150,000, or 10 per cent. of the whole crop, from the ravages of the red spider alone. Many individual growers have estimated their loss between $2,000 and $5,000 annually.

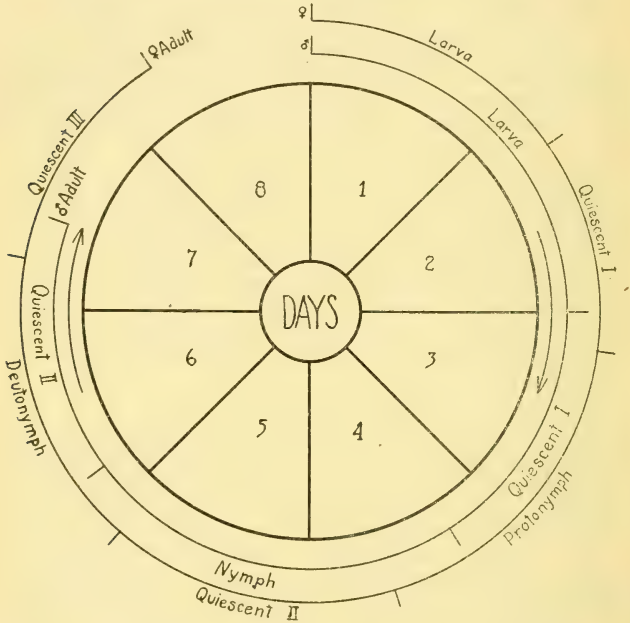
LIFE HISTORY.

An examination of infested cucumbers will reveal the presence of tiny transparent eggs, resembling minute dewdrops, attached to the under surface of a leaf or interwoven among the silvery threads which the mites are capable of spinning. In developing from the egg to the adult stage the red spider follows one of two distinct courses, depending on the sex.

With the female the egg hatches in about four or five days to a tiny colorless, six-legged form known as the larva, which feeds actively for a little over one day. At the end of this time the larva becomes firmly attached to the leaf and enters a quiescent premolting period which lasts for one day. At the termination of this time the skin is shed and there appears an eight-legged form called the primary nymph or protonymph, which feeds for approximately one day and then enters a quiescent premolting period. The duration of this period is approximately the same as that of the larval quiescent stage. From this premolting period there emerges the secondary nymph or deutonymph, which is probably the most voracious of the immature mites. The deutonymphal stage is divided into an active feeding period and a quiescent period, each of which requires one day for its completion, after which the adult female emerges from the deutonymphal molt. For the development from egg to adult it takes seven to eight days under favorable conditions of temperature. (See table on page 159.) The stages of the female red spider and their duration may be represented as follows: —

Egg.	Larva.	Quiescent I.	Proto-nymph.	Quiescent II.	Deuto-nymph.	Quiescent III.	Adult ♀.
4–5 days.	1¼ days.	1 day.	1½ days.	1¼ days.	1½ days.	1 day.	15–20 days.

Immediately following the deutonymphal molt the full-grown female establishes herself upon a cucumber leaf and feeds for about two or three days before oviposition takes place. During this short period it mates


♀
♂
Larva
Larva
Quiescent I
Quiescent I
Protonymph
Nymph
Quiescent II
Quiescent II
Deutonymph
♂Adult
Quiescent III
♀Adult
DAYS
1
2
3
4
5
6
7
8

and shows a tendency to migrate. Following this period for about eight to ten days it deposits about six eggs per day, thus making a total of fifty to sixty eggs laid by a single female. The average duration of life of the adult female in summer is about two weeks, but this period increases as the weather becomes colder.

The development of the male is very similar to that of the female, with the exception that the second nymphal stage is lacking. The other stages, however, require a little longer period for development, so that the time from the egg to the adult is only one day shorter than the development of the female. The different stages of development and the length of each stage of the male red spider may be represented as follows: —

Egg.	Larva.	Quiescent I.	Nymph.	Quiescent II.	Adult ♂.
4–5 days.	2 days.	1¼ days.	2 days.	1¼ days.	5–7 days.

Development of Female Mite from Egg to Adult.

DATE.	1.	2.	3.	4.
1916.				
May 21, A.M.,	–	–	–	–
P.M.,	Hatched.	Hatched.	Hatched.	–
May 22, A.M.,	Larva.	Larva.	Larva.	Hatched.
P.M.,	Larva.	Larva.	Larva.	Larva.
May 23, A.M.,	Quiescent I.	Larva.	Quiescent I.	Larva.
P.M.,	Quiescent I.	Quiescent I.	Quiescent I.	Quiescent I.
May 24, A.M.,	Molted.	Quiescent I.	Molted.	Quiescent I.
P.M.,	Protonymph.	Molted.	Protonymph.	Molted.
May 25, A.M.,	Protonymph.	Protonymph.	Protonymph.	Protonymph.
P.M.,	Quiescent II.	Protonymph.	Quiescent II.	Protonymph.
May 26, A.M.,	Quiescent II.	Quiescent II.	Molted.	Quiescent II.
P.M.,	Molted.	Molted.	Deutonymph.	Quiescent II.
May 27, A.M.,	Deutonymph.	Deutonymph.	Deutonymph.	Molted.
P.M.,	Quiescent III.	Deutonymph.	Quiescent III.	Deutonymph.
May 28, A.M.,	Quiescent III.	Quiescent III.	Quiescent III.	Quiescent III.
P.M.,	Molted (adult ♀).	Quiescent III.	Molted (adult ♀).	Quiescent III.
May 29, A.M.,	–	Molted (adult ♀).	–	Molted (adult ♀).
P.M.,	–	–	–	–

FEEDING HABITS AND DISPERSION.

A mite which has become full-grown, on finding a suitable spot on the under surface of the leaf, settles down to feed, and the results soon become apparent on the upper surface. At first this injury shows as a few small dead or corky specks, but as feeding continues these few are added to until we find a small area literally made up of them. The mite also immediately begins to lay eggs, which soon hatch into young mites. These, however, usually remain feeding in the immediate vicinity of their birth, thus causing more or less concentrated injury at different points on the leaf where older mites have established themselves, forming what might be termed different colonies. As these colonies increase in number the feeding areas also increase, until finally they coalesce and cover practically the whole leaf. This is now absolutely useless to the plant and worthless as a food supply for the large number of mites which inhabit it, and they therefore migrate to other leaves. This migration may be up the plant or may extend to the next plant, provided their leaves are in contact. This new plant may have hitherto escaped injury so that the basal leaves remain uninjured, while an infestation occurs part way up the plant. In natural dispersion the migration is nearly always by full-grown females previous to the egg-laying period. In the majority of cases dispersion within a greenhouse is accomplished wholly by natural agencies.

In artificial dispersion the most important factors are the men engaged in pruning, picking or "rolling up" cucumber plants. They pass from an infested to a non-infested plant, but carry over infestation on their clothing, hands or tools. This means of dispersion becomes exceedingly important when the plants have become so badly infested that webs have been spun over the leaves, as the pickers passing from one house to another carry infestation with them.

NATURAL ENEMIES.

Red spiders out of doors have a very large number of enemies belonging to widely different groups, nine groups of predacious forms embracing thirty-one species having been listed (McGregor, 1917) as attacking the red spider. Under greenhouse conditions, however, red spiders are exceptionally free from enemies. It appears that the red spider enemies are unable to develop in the high temperatures which are necessary for most greenhouse crops. In cucumber houses the writer has repeatedly examined infested leaves in the hope that some enemy would be found able to withstand greenhouse conditions and prove useful in the control of this mite, but these examinations have proved fruitless. On violets which are grown in a humid atmosphere and at a low temperature, a few predaceous mites belonging to the order *Acarina*, family *Gamasidæ*, are very beneficial.

INTRODUCTION TO EXPERIMENTS.

Before taking up the experiments conducted on the artificial control of red spiders a few facts will be summarized in order that the failure of some fumigants and sprays may be better understood.

Cucumber plants grown out of doors are very delicate and susceptible to injury of many kinds, while those grown in forcing houses are much more so. Therefore the sprays and fumigants which can be used with safety to the foliage are very few, while the red spiders are exceptionally hard pests to combat. These two opposing factors have been found extremely hard to satisfy.

Many greenhouse men ask the following question, "Why is fumigation not effective in controlling red spiders?" It has been known for many years that these mites are very resistant to fumigation with our ordinary poisonous gases, such as tobacco and hydrocyanic acid gas. To explain this peculiarity we must contrast the respiratory systems, through which all poisonous gases act, of mites and insects. The latter are efficiently controlled, while only a very few of the former succumb to such treatment.

In insects the respiratory system is composed of several large main air tubes which repeatedly divide, forming very small tubes which ramify into all parts of the body. This system of tracheal tubes opens to the exterior by several small segmentally arranged openings called spiracles, and through these the poisonous gas enters the air tubes, which conduct it to every tissue in the body, and produces sudden death.

Although the tracheal system of the red spider is better developed than in most mites, it is far simpler than in the majority of insects, containing a much smaller number of tubes.

The number and location of the spiracles in red spiders have not been determined because of their minuteness, but they are probably two in number and are situated in the vicinity of the head region. Therefore, although the red spider can be killed by fumigation with hydrocyanic acid gas, it is impossible to do so without severely damaging plant life, due to the concentration of the poisonous gas required.

An infested plant has at all times every developmental stage of the red spider on its leaves, but in artificial control methods we need to consider only three general stages.

1. *Egg Stage.* — At the present time no spray is known which will affect this stage without severely injuring the plant.

2. *Quiescent Stage.* — As explained under the life history, the young larvæ on hatching feed for a day, and then settle down on the leaf in a premolting or quiescent state during which time no nourishment is taken. These quiescent mites form a new chitinous layer beneath the old external skin covering of the preceding stage. Thus during this period a red spider has two chitinous layers covering the body instead of the normal one, and because of this it has been found very difficult to kill by contact sprays. By reference to the life history it will be seen that each female mite passes through three of these quiescent periods before reaching the adult state. If red spiders in this stage of development are not killed by the spray material recommended for control, it will be almost impossible to eradicate this pest unless sprayings are conducted daily.

As soon as the spray applied to an infested plant has evaporated, the mites will be found inactive, and many workers have concluded that all mites above the egg stage have been killed. However, if the leaves were kept under careful observation it would be seen that many of the mites quiescent at the time of application later molt and establish themselves. This point has been overlooked by former workers on the control of red spiders, but is a very important one.

3. *Feeding Stages.* — A large number of spray materials efficiently control mites in the active feeding stages, but because of their inefficient control of the quiescent stages have been discarded.

EXPERIMENTS CONDUCTED IN THE LABORATORY.

Fumigation Experiments.

Several fumigation experiments were conducted in the hope that some gas might be found effective for red spiders without being injurious to cucumber plants.

(*a*) *Sulfur Dioxide* (SO_2).

In many commercial forcing houses sulfur is burned between crops, in order to rid the house of all insects, fungous diseases and mites. To prove whether this was an efficient method, the following experiments were performed.

Powdered sulfur was burned at the rate of one-quarter of a pound per 1,000 cubic feet of space in a tight fumigating box containing a badly infested plant. After twelve hours' fumigation the plant was removed.

Results. — The cucumber plant was severely injured and died. All mites were killed, those quiescent failed to molt and the eggs did not hatch. This experiment was repeated several times and the results checked with those above.

Fumigation with sulfur dioxide is an inexpensive and efficient method of ridding an infested house of mites *between crops.*

Painting Sulfur on Steam Pipes. — This is an old practice of florists in combating the red spider, but has been proved beyond a doubt to be absolutely worthless.

(*b*) *Hydrogen Sulfid* (H_2S).

Potassium sulfid (liver of sulfur) dissolved in water has been widely recommended as an efficient spray for controlling red spiders, and it is claimed that its efficiency depends upon the fact that it combines with the carbon dioxide of the air, forming potassium carbonate and hydrogen sulfid according to the following formulæ: —

Monosulfid: $K_2S + H_2O + CO_2 = K_2CO_3 + H_2S$.
Polysulfid: $K_2S_5 + H_2O + CO_2 = K_2CO_3 + H_2S + 4S$.

As an insecticide it is claimed that this sulfid acts by virtue of its caustic properties and the hydrogen sulfid given off by its decomposition, this gas being for insects almost as poisonous as hydrocyanic acid gas.

To determine whether hydrogen sulfid could be used with safety to plants and still be effective in killing red spiders the following experiment was performed: a plant infested with mites was placed for twelve hours in a fumigating box containing a 1 per cent. atmosphere of hydrogen sulfid.

Results. — The plant was severely injured and died, while the mites and eggs were unaffected.

(*c*) *Carbon Bisulfid* (CS_2).

Experiments using carbon bisulfid at the rate of 2 pounds per 1,000 cubic feet proved to be inefficient in controlling the mites even after a twelve-hour fumigation. The plants in this case were not injured. Carbon bisulfid at a higher rate would be too expensive to use in commercial houses, and therefore further experiments were discontinued.

(*d*) *Benzene or Benzol* (C_6H_6).

Early in the experiments on the control of red spiders it was found that benzene vapor had a very active effect upon the mites. However, this proved to be only a temporary stupefication, and mites which had been removed from the fumigating box containing benzene vapor soon recovered in fresh air. The expense and danger accompanying the use of benzene precludes its use on a commercial scale.

Nitrobenzene and para-dichlorobenzene were experimentally used as fumigants, but proved to be as unsatisfactory as benzene, while nitrobenzene severely injured foliage.

Spraying Experiments.

At present the only known method of controlling red spiders is by the use of sprays. The majority of these act as adhesive sprays, while only a few are truly contact poisons.

(*a*) *Water.*

Water alone has been found very useful in the control of this pest on certain plants, such as the carnation, violet and rose. The usefulness of a water spray lies in the fact that frequent syringing dislodges many mites from the leaves. The majority of these fall to the moist ground and become permanently pasted into the mud. Frequent use of water also prevents the formation of webs, which are quite necessary as a means of travel and dispersal when a leaf becomes thickly populated. Although water is very useful in controlling these mites on certain plants, others cannot be grown in a humid atmosphere without being seriously attacked by fungous diseases, and this is especially true of cucumber plants. The tenderness of the forcing house cucumber also limits the usefulness of a strong stream of water.

(*b*) *Adhesive Sprays.*

1. *Flour Paste.* — Perhaps the most widely known and thoroughly tried adhesive spray is flour paste, recommended by W. B. Parker (1913) in controlling mites attacking hops in the Sacramento Valley, Cal. He found that flour paste made according to the following formula proved to effectively control 99 to 100 per cent. of the mites: 8 pounds of flour boiled in 8 gallons of water to form a paste, and diluted to make 100 gallons of spray.[1]

In order to obtain an accurate estimate of the effectiveness of this spray when used on cucumbers the following experiment was performed: a stock solution of flour paste was made and diluted according to Parker's formula. This spray was applied thoroughly to an infested plant.

Results. — The spray has excellent spreading qualities, and as an adhesive is quite efficient in controlling all mites which at the time of spraying are actively feeding. However, this spray does not affect either the hatching of the eggs or the emergence of the mites from the quiescent stages.

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[1] In a recent government bulletin McGregor and McDonough recommend the use of laundry starch, thus simplifying the process of cooking in forming the stock paste solution.

2. *Soap.* — The addition of soap to a spray material increases its spreading qualities and at the same time adds to its adhesive properties. For red spider control soap is inefficient as a contact poison, but if used in fairly concentrated solutions it proves to be an excellent adhesive spray.

Ivory soap used at the rate of 1½ pounds in 25 gallons of water was tried as a spray and found to be as effective as flour paste (8–8–100), with the advantage of being much easier to make and not requiring constant agitation.

Results. — After this spray has been applied the water evaporates, leaving a brittle film of soap over the mites, which is fairly efficient in sticking these pests to the leaves. However, nearly all mites which are in the quiescent stage molt and establish themselves, and quite a few of the actively feeding mites are able to break the brittle film of soap covering their bodies and thus become liberated to feed on the leaf as before. The eggs are not affected.

A common brand of fish oil soap, at the rate of 1 pound in 10 gallons of water, was applied to mites on cucumbers. The efficiency of this over ordinary soap proved to be very little, if any.

(c) *Sulfur and Compounds of Sulfur.*

Sulfur and many of its compounds have been recommended for the control of red spiders attacking various plants. The following have been tried thoroughly, but have proved, for the most part, inefficient.

1. *Dry Sulfur.* — In southern California, where the temperature is high, dusting plants early in the morning so that the dew on foliage will cause the particles of sulfur to adhere has been found very successful, especially upon low-growing plants. The use of resublimed or flowers of sulfur on plants which are not prostrate has proved very unsatisfactory as a control for red spiders. Many of the market gardeners of Boston have thoroughly tried out this method without any material success. Several experiments were conducted, but dusting did not seem to affect the red spiders in the least, even though the temperature was high.

2. *Sulfur as a Liquid Spray.* — This spray has been recommended for controlling red spiders, but experimentally proves to be of very little value.

3. *Sulfur Compounds.* (*a*) *Potassium Sulfid* (*Liver of Sulfur*) K_2S. — This spray has been recommended by McGregor as being very effective in controlling red spiders attacking cotton. Using 3 pounds of potassium sulfid to 100 gallons of water, McGregor found that 100 per cent. of the mites on cotton were killed by this spray. This is an easily prepared material which may be applied with safety to foliage, but at the present time, on account of the increasing demand for potassium salts for use in the manufacture of munitions and fertilizers, this is very difficult to

obtain, while the price is rather high. In using this material on cucumbers it is necessary to add soap to the solution in order to increase its spreading qualities.

Results. — This spray proved to be efficient in controlling actively feeding mites, but only a few of those quiescent failed to molt. The eggs were not affected.

(*b*) *Calcium Sulfid* (CaS_2). — This spray proved to be of little value as it killed but few mites. Soap cannot be added to this solution as it forms an insoluble calcium soap which is precipitated. Had this material proved of value it could be obtained more cheaply in lime-sulfur, of which it is a constituent, than in the form of the pure white calcium sulfid.

(*c*) *Sodium Sulfid* (Na_2S). — To determine whether a substitute for potassium sulfid could be obtained by the use of sodium sulfid, a spray was made by the following formula: —

	Pounds.
Commercial NaOH,	2½
Flowers of sulfur,	5

After solution is complete add water to make 100 gallons of spray.

Results. — Although this spray proved to be as effective in killing all actively feeding mites as did the potassium sulfid solution, its effect on the quiescent stages was materially less. The eggs were not injured.

(*d*) *Soluble Sulfur.* — This is a commercial compound made up principally of sodium sulfid, and as a spray the results check with those given above, with the exception that this spray is very apt to injure the foliage.

(*e*) *Barium Sulfur* (B. T. S.). — This material, used at the rate of 3 pounds to 50 gallons of water, is not injurious to foliage, but is inefficient in controlling mites. Soap cannot be added, as it forms an insoluble barium soap.

(*f*) *Lime-sulfur and Nico-fume Liquid.* — This has been recommended as a spray for spider mites as well as the clover mite (*Bryobia*), and has the following composition: —

Lime-sulfur, commercial (quarts),	2
Nico-fume (pint),	½
Water (gallons),	25

Results. — The application of this material caused considerable injury to the cucumber foliage, while it was only fairly efficient in controlling the mites. Several greenhouse men have sprayed with dilute lime-sulfur solution, but have found it both inefficient in controlling these pests and injurious to the foliage. Nicotine sprays are also inefficient when used alone.

(*d*) *Oil Sprays.*

1. *Sprays containing Petroleum Oils.* (*a*) *Arlington Oil.* — This is a chemically miscible oil containing approximately 90 per cent. petroleum oil. Used at the rate of 1 part oil in 50 parts of water it was found effective

in controlling aphids and thrips, but killed only 50 per cent. of the actively feeding mites. At the above strength this spray severely injured cucumber foliage, and even when diluted to 1 part oil in 100 parts of water, injury still occurred.

(*b*) *Arlington Oil and Black-Leaf-40.* — Formula: oil, 1 part to 125 parts of water; Black-Leaf-40, 1 part to 2,000 parts of water. This combination spray is much more active than the ingredients used separately, but is injurious to the cucumber foliage.

(*c*) *Kerosene Emulsion.* — This is recommended as being efficient in controlling red spiders, but it severely injures tender foliage.

2. *Sprays containing Vegetable Oils.* (*a*) *Lemon Oil.* — This is manufactured by the Lemon Oil Company, Baltimore, Md., and is at present sold at $1.75 per gallon in 5-gallon lots. It is a completely saponified oil soap, and is guaranteed to contain the following ingredients: —

	Per Cent.
Soap,	6
Vegetable oil,	3½
Potassium carbonate,	½
Terabenthine (Turpentine?),	5
Water (not over),	85

Of the many commercial insecticides used experimentally in the control of red spiders this proved the most satisfactory.

Results. — Used at the strength of 1 part lemon oil in 20 parts of water, or 1 pint in 2½ gallons of water, it killed all actively feeding mites, as well as those in the quiescent stage, without injuring the foliage. The eggs are not materially affected by this spray. If young potted cucumber plants are dipped in the above mixture some injury will result to the terminal growing point, but if the plants are sprayed this injury does not occur.

During the spring and summer months of 1916 this spray was thoroughly tried out on a commercial scale, and proved to be very satisfactory, but its expensiveness precludes its free use as a general spray for red spiders.

(*b*) *Experiments on the Duplication of Lemon Oil.* — With the cooperation of Dr. E. B. Holland of the Massachusetts Agricultural Experiment Station a number of spray materials were made in order to determine the killing agent in lemon oil, and for the purpose of duplicating the efficiency of this oil by a substitute which would be less expensive. The following table will briefly show the composition of these mixtures and their relative effectiveness in controlling red spiders: —

	MIXTURE.										
	Lemon Oil.	**1.**	**2.**	**3.**	**4.**	**5.**	**6.**	**7.**	**8.**	**9A.**	**9B.**
Soap: —											
B. T. Babbitt's (per cent.),	–	–	–	–	6.00	–	4.50	–	–	–	–
Powdered soap (per cent.),	–	–	–	2.50	–	–	–	–	–	–	–
Soap unknown (per cent.),	6.00	–	–	–	–	–	–	–	–	–	–
Borax soap (per cent.),	–	6.00	–	–	–	–	–	–	–	–	–
Other materials: —											
Sodium hydrate (per cent.),	–	–	1.75	2.00	1.00	1.25	.50	1.66	3.00	3.00	3.00
Rosin (per cent.),	–	–	1.50	2.00	–	–	–	–	2.00	2.00	2.00
Potassium carbonate (K_2CO_3) (per cent.),	.50	–	–	–	–	–	–	–	–	–	–
Oils: —											
Citral (per cent.),	–	4.00	–	–	–	–	–	–	–	–	–
Lemon grass oil (per cent.),	–	–	1.75	3.50	3.50	–	–	–	–	–	–
Linseed oil (per cent.),	–	–	–	–	–	4.00	–	5.00	10.00	10.00	10.00
Turpentine (per cent.),	5.00	5.00	2.50	5.00	5.00	2.50	5.00	–	5.00	5.00	5.00
Unknown vegetable oil (per cent.),	3.50	–	–	–	–	–	–	–	–	–	–
Water (per cent.),	85.00	85.00	92.50	85.00	84.50	92.25	90.00	93.34	80.00	80.00	80.00
Dilution,	1-20	1-10	1-5	1-10	1-10	1 5	1-5	1-1½	1-15	1-15	1-8
Efficiency,	[1]	[2]	[2]	[2]	[2]	[2]	[2]	[1]	[1]	[2]	[3]

[1] Efficient. [2] Not efficient. [3] Fairly efficient.

(*c*) *Linseed Oil Emulsion.* — Thus, out of nine mixtures, only those containing linseed oil proved at all promising. Mixtures 7 and 8 were rather poorly saponified (chemically), while 9*a* and 9*b* were completely saponified; but 7 and 8 proved efficient, while 9*a* and 9*b* were not. This could only be explained by the fact that the free linseed oil was really the toxic agent, and when it was only partly saponified there remained some free linseed oil which established the efficiency of the spray. Upon this supposition were based other preparations containing linseed oil mechanically emulsified in a solution of soap in water. These emulsions proved to be efficient when a 1 per cent. oil spray was used.

Two types of linseed oil emulsion may be made, depending upon the length of time these emulsions are to be retained before use.

Experimentally it was found that the most stable stock emulsion could be made as follows: one-eighth of a pound of Ivory soap (one-half a 5-cent cake) dissolved in a pint of very hot water. After the soap is completely in solution add 1 pint of cold water followed by the addition of 1 pint of raw linseed oil. The oil should be completely emulsified by the use of a bucket pump. This solution is stable, provided the water contained in it is not allowed to evaporate. In using this stock emulsion, especially after it has been kept for some time, it is best to mix one part of stock with an equal volume of water before diluting to desired strength. One part of stock emulsion in 20 parts of water proved to be efficient in killing mites, both in the quiescent and feeding stages.

If spraying is to be done soon after mixing the emulsion it is best to increase the amount of water and soap, and make the emulsion as follows: shave 6 ounces of Ivory soap (1½ 5-cent bars) into 1 gallon of hot water. Add 2 quarts of cold water to cool the solution, then add 1 quart of raw linseed oil and emulsify with a bucket pump. This emulsion, used at the rate of 1 part in 9 parts of water, is very efficient, killing quiescent and feeding mites without injury to leaf tissue.

Soy bean oil substituted for linseed oil proves to be efficient, and in some localities could be used to advantage.

Action of Linseed Oil Emulsion upon Mites. — The majority of oils used as insecticides are regarded as contact poisons. These poisonous oils are supposed to enter the body of the insect, either directly through the thin membraneous chitin of the body segments or by entering the spiracles, where they immediately pass through the tracheal lining and produce an active effect upon the internal structures essential to the life of the insect.

In a previous part of this paper it has been shown that the spiracles are very few, — probably two in number, — and that the body of a red spider is covered by a rather thick and continuous coating of chitin. For these reasons sprays which prove effective in killing aphids are of little value when applied to mite-infested plants.

Many of the spray materials which have given partial success in controlling mites have a marked adhesive action, and from this property linseed oil emulsion derives its efficiency. The spray as made (see "Repressive Measures") contains the amount of soap necessary to hold the oil in suspension and give the spray material excellent spreading qualities. Raw linseed oil contains two types of oils, — (1) drying oil and (2) resinous oil. Upon this fact is based its usefulness in paints, as well as its efficiency as a red spider spray.

A leaf thoroughly covered by the spray soon becomes dry, the water evaporating, while the oil and soap become more and more concentrated as this evaporation continues. Finally there is formed a very thin layer of oil and soap which gradually settles down on to the leaf surface, covering all mites which were feeding on the leaf at the time of application. This film gradually envelops the mite, and the volatile parts of the linseed oil are given off, leaving behind a resinous or waxy oil which securely cements the legs of the mite to itself and to the leaf. Thus the mite is helpless, and the waxy residue of the linseed oil remains, sticking the mite until it dies of starvation. Without doubt some of its effectiveness may be due to its being a contact poison, but its most important quality is its adhesiveness.

Summary of Materials found to be Efficient Experimentally.

No fumigant was efficient in killing red spiders without severely damaging cucumber plants.

Sulfur burned to form sulfur dioxid proved to be very effective in killing all stages of mites. Although this gas is deadly to plant life, its application as a fumigant to rid empty houses of all mites is extremely useful.

Many spray mixtures proved to be efficient in controlling actively feeding mites, but did not affect those in the quiescent stages of development. For the control of all stages above the egg stage lemon oil, a commercial product, and linseed oil emulsion proved to be the most satisfactory. Soapy solutions should also receive some attention as among the most readily prepared spray materials, although their efficiency is only temporary and treatment must be repeated often in order to control these mites.

EXPERIMENTS CONDUCTED IN COMMERCIAL GREENHOUSES.

The materials found to be most efficient in the laboratory experiments were applied to cucumber plants in commercial establishments in order to determine the practicability of spraying for the control of these mites before any recommendations were made.

It was found impossible for the writer to be stationed at these greenhouses during the whole spraying period. Therefore the efficiency of these sprays under commercial conditions has been determined largely by the statements of the growers, checked by more or less frequent personal observations.

LEMON OIL.

The first of these commercial experiments commenced during May, 1916, and continued until the middle of June. Lemon oil, 1 part in 20 parts of water, was thoroughly tested in several greenhouses, and in all cases the spray proved very efficient, provided it was thoroughly applied to the infested plants. At the time the first commercial applications were made the plants were nearly full-grown, and the mites were at that time rapidly spreading through the houses. All that could be expected of this spray was to hold the red spiders in check, so that they would not materially damage the whole house before a good crop of cucumbers had been picked. Owing to the scarcity of labor it was found impossible to apply sprays at weekly intervals, and therefore the results were not as satisfactory as they would have been under other conditions. However, these sprayings held the red spiders in check and prolonged the life of the cucumber plants, which would have died early in the season had no treatment been applied.

In several instances young potted cucumber plants were dipped in a 1 to 20 dilution of lemon oil as they were being set in the greenhouse. This proved to be injurious to the succulent leader, although the leaves gave no indication of injury.

LINSEED OIL EMULSION.

During the summer of 1916 experimental work on the determination of the killing property of lemon oil led to the discovery of linseed oil emulsion and its efficiency in controlling mites. This emulsion has received a very thorough trial in commercial greenhouses this season (1917), and proves to be satisfactory in many respects. The ingredients are always at hand, the initial cost is low, being one-fourth that of lemon oil, and the method of preparation is simple.

Experiment No. 1.

Early in the spring of 1917 this spray mixture was thoroughly tested on a commercial scale in greenhouses located in Watertown, Mass. This range is naturally divided into two groups. Group I. contained the oldest cucumber plants and Group II. the youngest. It was decided that applications should be made to the youngest plants, although they were really too old for effective spraying. The cucumber plants became badly infested in the seed-plant house before being set out. Therefore this infestation became serious soon after the plants were transplanted to the greenhouses. Severe pruning was resorted to, but this did not hold the mites in check. For efficient control, these plants should have been thoroughly sprayed at the time they were transplanted.

Group II. consisted of three greenhouses. In greenhouse No. 1 the plants were very heavily infested, and were 5 feet tall at the time of the first application. In No. 2 the plants were $2\frac{1}{2}$ feet tall and generally infested, although not showing any noticeable injury to the plants from the red spider attack. In No. 3 the plants were 4 feet high and rather severely infested. In each of these houses three applications were made at weekly intervals.

The final results of these experiments are as follows: the greenhouses of Group I. were not sprayed, and though the plants were very little older than those in Group II. they died from the red spider injury after being in the range approximately three months. In Group II. the plants were sprayed and produced fruit for over a month longer than the unsprayed plants of Group I. Houses No. 1 and No. 3 contained such large cucumber plants that a thorough application of a spray was found impossible, but the ravages of these mites were checked during the spraying period. Although a complete control was impossible, the productive life of the crop was lengthened approximately one month. In house No. 2, containing the youngest cucumber plants in Group II., the control was much more efficient, primarily because the plants were smaller and a thorough spraying could be given them. However, even these plants were too large to insure a thorough application after the first spraying.

Experiment No. 2.

Further tests of the efficiency of linseed oil emulsion were made in commercial greenhouses at Arlington, Mass. In this establishment all plants were infested in the seed-plant house while still in pots. Soon after they were set in the greenhouses the first spray was applied, and one week later the second application was made. These two applications were made at the proper time, and controlled the mites so effectually that during midsummer some of these houses were yielding good crops, while only a few scattered plants were beginning to show marked red spider injury. At approximately the same time in former years the plants in these houses have been severely infested and dying from the ravages of the red spider. This range of greenhouses consists of twelve large houses, and therefore it is not surprising that the whole establishment could not be thoroughly covered each week.

An excellent demonstration of the efficiency of linseed oil emulsion was made in the seed-plant house. As stated above, when the cucumber plants were still in pots in this house they were noticeably infested by red spiders. The grower, knowing that this house contained many mites, determined that sprayings should be given with special care, in order to eradicate these pests. Soon after the potted plants were set out in the seed-plant house the first application was given, care being taken to cover thoroughly all the leaf surface. One week after this the second thorough spraying was applied. These applications were made so thoroughly that very few if any mites which originally infested the cucumber plants survived, and the plants attained full growth without showing any red spider injury.

CONCLUSIONS DRAWN FROM COMMERCIAL SPRAYING EXPERIMENTS.

Sprayings conducted on bright, sunny days with a rather high temperature in the greenhouse resulted in slight injury to the edges of the leaves, but if applications were made on cool, cloudy days this injury did not occur.

For a thoroughly efficient control at least three applications should be given the cucumber plants at weekly intervals, as soon after they have been set out in the greenhouses as possible.

PREVENTION.

The writer has been unable to conduct a thorough test in eliminating red spiders from the whole range by cultural methods, because it was found impossible to procure an establishment which would serve for this purpose. In commercial greenhouses many factors enter into the red spider problem which cannot be solved unless a suitable range is found which will eliminate these confusing factors in order that some definite knowledge may be gained by using preventive measures. However, under greenhouse conditions, it is the writer's firm conviction that the red spiders can be totally exterminated from commercial ranges by clean culture, both within and outside the greenhouse. It is hoped that some experimental work may be conducted on this important control measure in the near future.

CONTROL MEASURES.

The general biology and development of experimental and commercial control measures have already been discussed, but only in a general way. Under this heading the methods used for the prevention and repression of red spiders will be taken up more in detail. Having established the efficiency of the repressive measures, only the preparation and application of spray materials will be considered.

PREVENTIVE MEASURES.

The solution of the red spider control problem in cucumber greenhouses should be accomplished through preventive efforts rather than by repression, if it is to be done most economically. The commercial grower should do everything possible to eliminate these pests, both within and outside his greenhouses.

In the majority of cases cucumber plants are infested either in the plant house or soon after they have been set out in the greenhouse. The origin of this infestation may be weeds which have harbored mites throughout the winter inside the greenhouse, or weeds and grasses immediately surrounding the house at the base of which the mites winter over and migrate into the greenhouse early in the spring. The first is very important when plants are started very early in the season, while the second is of importance only after the warm days of spring have started these outside weeds.

Fumigation of Greenhouses and Equipment with Sulfur Fumes.

Immediately before setting the cucumber plants in a house, and before fumigation is begun, all boards which are to be used either between the cucumber rows or to make "A" trellises should be taken inside the greenhouse. Do not lay the boards on the ground, but stand them against the steam pipes or in some similar manner to allow the poisonous gas free access to all parts. Other equipment which has been in any way connected with a previous infestation and is to be used during the cucumber season should also be placed in the house for fumigation. Do not introduce living plants until after a thorough fumigation and a subsequent airing of the houses, as sulfur fumes are deadly to plant life.

In fumigating, each house should be tightly closed and sulfur used at the rate of one-third of a pound to every 1,000 cubic feet of space. (Increase to one-half pound in case of houses that are not fairly tight.)

Directions for Fumigation. — Weigh the required amount of sulfur and divide it into four equal parts upon pieces of paper. This is about the right number for a 150-foot house. Metal pans with plenty of breadth are perhaps the best containers for the fumigating operation. First cover the bottom of each pan with chips that have been soaked in kerosene, and distribute these containers at various points through the house, placing beside each the sulfur to be used. When all is in readiness set fire to the chips, and when these are burning well drop in the sulfur. Be certain that the sulfur has ignited and then withdraw from the house. Allow the sulfur fumes to act for at least twelve hours before opening the house. This fumigation may be done during the day or at night, according to the convenience of the grower, and if the method is followed out carefully the red spiders will be completely exterminated within the house.

Special attention should be paid to the house in which potted cucumbers are to be grown, and fumigation should be very thorough, for in many cases the seat of infestation occurs here. At the conclusion of the cucumber crop in the late summer the whole house should be fumigated with sulfur before the plants have died, thus preventing the borders from becoming infested from thrown-out cucumber plants, and reducing the number of red spiders which would otherwise winter over and attack the next cucumber crop.

Destroying Outside Sources of Infestation.

The next problem which confronts the grower is to eliminate the possibility of infesting the houses from outside sources. Investigation has shown that many weeds and grasses, often found around greenhouses, serve as breeding places for these pests, and undoubtedly are the source of inside infestation. In the fall red spiders are found in large numbers on these grassy borders, and being capable of wintering over out of doors, it follows that a large percentage of those found in the fall will also be present in the spring, and are quite certain to migrate to the more attractive cucumber plants within the greenhouse.

Methods of Exterminating Grassy Borders.

1. The border for at least 10 feet away from the house should be thoroughly cultivated, preventing the growth of weeds throughout the season.

2. Where cultivation is not practicable, burning the border may be resorted to.

3. If neither of the above methods can be employed, kill all vegetation around the greenhouse by spraying with sodium arsenite used at the rate of 1 pound to 20 gallons of water. It must be remembered, however, that sodium arsenite is a poison, and care should be taken to prevent animals from grazing on treated borders. Repeat as often as necessary.

Elimination of Artificial Dispersion.

As described under "Feeding Habits and Dispersion," the most important factors in artificial dispersion are the men working in the greenhouses. The grower should systematize, as far as it is practicable, all work which must be done in his houses according to the infestation; for example, in two greenhouses, one showing red spider injury, the other apparently free, pruning or "rolling up" of plants should first be done in the house apparently free from infestation, and later in the infested house. Also in picking cucumbers, the young houses — which usually are not as badly infested as older ones — should be picked first, and older, badly infested houses last. Special care should be exercised not to allow the men who have finished picking in a badly infested house to start pruning or "rolling up" a very young house. Baskets used in picking cucumbers should never be used in a younger house as a receptacle for pruned parts of young plants.

The writer realizes that these recommendations are not all applicable under commercial conditions, but every precaution which is practicable should be taken if artificial dispersion and infestation are to be reduced.

REPRESSIVE MEASURES.

During the early stages of infestation it is frequently found advisable to destroy plants which are found to be badly infested. These badly infested plants should be pulled out before the leaves begin to die, so as to prevent dispersion due to lack of food.

If a few leaves, usually near the ground, are badly infested the pruning of these will lessen the numbers of mites materially. In all cases, whether a plant has been pulled or pruned, the red spiders on these leaves should be destroyed by burning. Do not throw them outside of the house, but destroy them immediately, thus eliminating the chance of infesting plants surrounding the greenhouse. Pruning is especially useful when judiciously applied to the young plants in a greenhouse. Such pruning should be supplemented by spraying for a thoroughly efficient control.

Spraying.

If there is any possibility of infestation, spraying should commence soon after the cucumber plants have been set out in the greenhouse. If spraying is done at this time less material will be used, and a very thorough application can be given in a minimum amount of time. In experiments conducted in commercial greenhouses it was found that red spider sprays applied to young cucumber plants gave very satisfactory results, while on older plants these sprays did not prove as efficient. This can be explained by the fact that a good-sized cucumber plant has a large amount of leaf surface which must be thoroughly covered by the contact spray if efficiency is to be expected. This is economically impossible after the plants have become nearly full-grown, because of the length of time and amount of material necessary to accomplish it. Early spraying will control red spiders at a minimum expense of time, labor and materials.

Linseed oil emulsion is especially adapted for use in commercial greenhouses on a rather large scale.

If only a few plants need to be treated, lemon oil, manufactured by the Lemon Oil Company, Baltimore, Md., may be purchased at nearly all stores carrying insecticides. This, diluted at the rate of 1 part in 20 parts of water, gives a very efficient spray, but for commercial spraying this material is too expensive.

Soapy solutions sprayed upon delicate plants on several successive days prove to be useful. In making this solution a high-grade soap (Ivory soap) should be dissolved at the rate of 4 ounces in 3 or 4 gallons of water.

Preparation of Linseed Oil Emulsion.

(*a*) The necessary articles for preparation are as follows: —

1. Bucket pump.
2. Container or mixing tank. This should hold at least 8 or 9 gallons. For this purpose a small washtub is perhaps the most available. Pails may be used, provided the materials are mixed proportionally.
3. Ivory soap.
4. Raw linseed oil.
5. Hot water.

(*b*) The following proportions of materials for 100 gallons of spray are used: —

1. Five gallons of hot water.
2. One and one-half pounds of Ivory soap. (Six 5-cent cakes or three 10-cent cakes.)
3. One gallon of raw linseed oil.

(*c*) Steps in the preparation of stock solution follow: —

1. Put the required amount of hot water in the container.

2. Shave the Ivory soap into this and stir until completely dissolved.

3. If at this time the temperature of the soap solution is too hot for the hand to bear, dilute with 1 gallon of cold water and let it stand until about body temperature or lukewarm. The cooling of this solution is necessary in order to prepare a permanent emulsion; otherwise the oil will come to the surface on standing (see No. 6). It also prevents the chemical and physical killing properties of the linseed oil from being changed by heat.

4. Add slowly, while stirring vigorously, 1 gallon of linseed oil.

5. Completely emulsify by using the bucket pump. Pump the emulsion from the container through the pump and back into the container again, keeping the nozzle below the surface of liquid. Five minutes' vigorous pumping should completely emulsify this solution.

6. Set aside for a few minutes while preparing spray tank in order to see that oil does not come to the surface.

(*d*) The following are directions for the preparation of spray tank and spray: —

1. Fill the 100-gallon spray tank about one-half full of water. If the water used is too cold, upon the addition of the stock solution the soap will solidify into small lumps, thus spoiling the emulsion. This may occur early in the spring, when the water is very cold, but later in the season ordinary tap water may be used without danger of the soap solidifying on the addition of the stock solution.

2. Add stock solution made above. (See (*c*) 1, 2, 3, 4, 5, 6.)

3. Agitate. (If lumping occurs, the addition of a few pails of hot water will remedy this.)

4. Fill the 100-gallon spray tank.

Application of the Spray.

Outfits and Methods of Spraying. — In commercial greenhouse spraying either a barrel pump or power sprayer should be employed, the latter being the more economical, provided it is available and the size of the establishment warrants its use. For spraying a few plants, or in a very small greenhouse, perhaps the most satisfactory outfit consists of a compressed air sprayer.

The length of hose necessary in spraying cucumber houses depends upon the size of the house and the method of growing cucumbers. If the vertical trellis system is used, in most cases it is best to have the hose of sufficient length to reach from the sprayer down the middle aisle and across the opposite end of the house, thus eliminating the necessity of changing the sprayer during the spraying operations. By passing in a zigzag manner across the house and gradually working backward the house may be thoroughly covered in the least amount of time. If cucumbers are grown on the "A" trellis system the man spraying should travel up on one side of the row and back on the other. In either case a boy should be employed to guide the hose, so that it will not injure the plants as it is pulled from one row to the other.

These are the most common methods of spraying, but there are many modifications which the grower can make according to the conditions surrounding his houses and the manner of growing his plants.

An extension rod made from small piping with an elbowed tip or angle nozzle is absolutely necessary for thoroughness in spraying. If cucumber plants are grown on the vertical trellis system the extension rod should be about 2½ feet in length, while if grown on the "A" trellis system the rod should be 4 feet in length, as this will allow the man spraying to reach the basal leaves of the plants readily. It is perhaps more satisfactory to use a 45° angle nozzle, several of which may be purchased (*e.g.*, Friend and Simplex angle nozzles), thus eliminating the necessity of a separate elbow.

Methods of Application. — From the fact that the red spider as a rule passes its entire existence upon the under surface of a single leaf, early in the season, when the plant is only slightly infested, it is plainly necessary in spraying to cover the entire under side of every leaf. Special attention should be paid leaves showing typical red spider injury, especially the lower leaves of the plant, near the ground, as these are usually most severely infested. To facilitate this under-surface spray an extension rod with an elbow tip or angle nozzle is essential.

The pressure necessary in power spraying varies from 50 to 125 pounds, depending upon the type of nozzle. Do not allow the spray to bombard the under surface of the leaf if a coarse nozzle is used. As this linseed oil emulsion is a contact spray, it is necessary that the whole under surface of a leaf should be covered by a film of this material. If the spray is deposited on the leaf in fine droplets which do not run together, this can be remedied by the adjustment of the pressure until they unite to form a film. If a coarse nozzle is used, as the Simplex, a low pressure will be required for film formation, while with a fine nozzle, as the Friend, a higher pressure will be necessary. A preference should be given the fine nozzle and high pressure, as this is less apt to injure the leaves, while it proves very satisfactory in forming the film. The success or failure of the spraying depends upon this film formation and thorough application of the material.

When Applications should be made. — In general greenhouse practice spraying on bright days is and should be the rule, as with sunshine there is less danger that conditions favorable for disease will result. In the application of the linseed oil emulsion, however, spraying conducted on sunny days with a rather high temperature in the greenhouse may result in a slight injury to the edges of the leaf, while if spraying is done on cool, cloudy days no injury is caused by the applications. Therefore, as far as possible, spraying for the red spider should be done on cloudy days when the temperature in the house is not over 80°. The injury on bright days has never been serious, but should be eliminated as far as possible by proper management of greenhouse temperature and the selection of suitable days for spraying.

In order to effectively control red spider infestations, at least three sprayings given at weekly intervals are necessary.

The first spraying should usually be applied one week after the plants have been set in the greenhouse. If the young plants show mite injury before this time the application should be made as soon as possible. Usually young cucumber plants do not appear to be affected early in the season. However, on closer examination it will be found that the majority of these plants harbor a few mites which, if allowed to develop unhindered, will later become so numerous, and the plant so large by the time injury is noticeable, that an efficient control will be found extremely difficult and expensive.

Since this spray does not destroy red spider eggs it is clear that a second application is necessary to kill the individuals which were eggs at the time of the first spraying. This should be applied seven to eight days after the first. If the second spray is not applied at the proper time it will be almost impossible to control these pests, for many mites will have become adult and laid eggs unless the application is made as recommended.

Some mites are sure to escape the first and second sprayings, and therefore a third application must be given in order to kill these mites, which if not controlled will rapidly multiply and severely injure the plants.

As previously mentioned in the discussion of the "Economic Importance of the Pest," the loss to cucumber growers due to red spider infestation consists in shortening the life of the plant during its productive period. It is absolutely essential that these three sprayings be made as directed, otherwise the producing period of the plants will be reduced at least one month.

Under normal conditions the few mites found early in the season reproduce rapidly until finally the plant becomes seriously affected by the injuries caused by their progeny, and usually dies before producing a full crop. If the mites are held in check by weekly applications early in the season the length of the period during which these regular applications are made will later be added to the adult life of the plant. The longer the spraying period the longer the productive life of the cucumber plant.

It is therefore of great financial importance to the grower to see that these sprayings are thoroughly applied at weekly intervals during the early life of the crop.

Cost of Spraying. — The comparative cost of 100 gallons of spray containing lemon oil and linseed oil is as follows: lemon oil, $8.75; linseed oil emulsion, $1.50.

If sprayings are made with a power sprayer it will take a man, with the help of a boy, approximately three hours to spray thoroughly a greenhouse containing 1,600 cucumber plants about 4 feet high. The material used will amount to 100 gallons. Thus the cost of one spraying when the plants are nearly half grown is approximately $3.

Spray materials,	$1 50
Man, three hours,	1 00
Boy, three hours,	50
	$3 00

This is a fair estimate of the cost of the third spraying. The first and second sprayings taken together should cost approximately $3. Thus, for three applications of linseed oil emulsion to 1,600 plants, the investment for labor and materials will be approximately $6. This should be considered insurance on the crop. At the above rate the cost for three applications is less than one-half cent per plant.

The original investment for spray materials and labor will be repaid many times over by prolonging the fruit-bearing period of the plants.

CONTROL OF RED SPIDERS ATTACKING OTHER CROPS.

Perhaps a few words relative to the control of these mites attacking some of the other crops will prove useful, especially to florists. Although the writer has confined most of his attention to the control of this pest on cucumbers, it is reasonable to suppose the same control measures will give as satisfactory results in eliminating this pest on other plants. While this is true, a few factors must be thoroughly understood in order to procure these results.

On small or rather smooth-leaved plants, such as the violet, rose, carnation, sweet pea and bean, the linseed oil emulsion spray as used on cucumbers does not prove as satisfactory. The reason for this is that the greater part of the spray applied to these plants runs off the leaf, and not enough linseed oil is deposited on the mites to render them helpless. To remedy this difficulty the stock linseed oil emulsion should not be diluted as much as recommended for cucumber spraying. In some cases where very delicate plants are to be sprayed the same dilution may be made, but the solution of soap should be stronger.

In spraying cucumbers a 1 per cent. linseed oil mixture is used. On plants such as the violet it is best that the original linseed oil stock solution be diluted only one-half as much, making a 2 per cent. linseed oil mixture and a more concentrated soap solution.

In the majority of cases proper experimentation by the grower will furnish satisfactory evidence for the required dilution for efficiency on his special crop.

During July and August, 1917, the writer had the opportunity of thoroughly testing the efficiency of this 2 per cent. linseed oil emulsion for the control of red spiders attacking violets in the field at Mr. William Sims' greenhouses, Cliftondale, Mass. This field of violets, containing about

100,000 plants, was sprayed, using a power sprayer, three times between July 15 and September 1. The object of this spraying was not to rid the plants of red spiders, although this undoubtedly could have been accomplished, but to keep their numbers so reduced during the dry summer months that they could not seriously injure the new and tender foliage or kill the plants as they had done in previous years.

The results were entirely satisfactory, and the violet plants were kept practically free from these pests. Those plants rather seriously damaged before spraying began regained their dark green foliage, and during the middle of August only a few leaves could be found in the field showing typical red spider injury. Thus the damage caused by red spiders was reduced to a minimum by spraying, while in previous years and under similar conditions they had practically stripped the plants of their foliage.

The difficulty of thoroughly applying a spray to the lower surface of the leaves of a low-growing plant is well recognized, for our modern nozzles are not adapted to this type of spraying. This difficulty, however, may be overcome in violet spraying by the use of a simple spray nozzle consisting of a "Skinner System" plug. This plug is often used in greenhouses, where it is inserted at intervals in the side of a water pipe. Water passes from the pipe through a small hole in the center of the plug, and then strikes a curved lip which transforms the solid stream to a fine, fan-like spray. This plug is placed in the end of an extension rod 5 feet in length, made from one-eighth-inch piping. The rod is then bent until the fan-like spray travels parallel to the surface of the ground. This type of nozzle proved very satisfactory, and could be held close to the plant without injuring the leaves.

SUMMARY.

The common greenhouse red spider (*Tetranychus bimaculatus* Harvey) is very generally distributed throughout the United States, extending from Maine to Florida, and westward to Texas and California, only a few States in the western arid region being exempt from the ravages of this pest.

The red spider is very cosmopolitan in its feeding habits. In market-garden greenhouses the most important vegetable attacked is the cucumber. In floriculture greenhouses the rose, violet, sweet pea, carnation and chrysanthemum are seriously injured. The most important outside plants, as far as the greenhouse man is concerned, are those found around most greenhouses, consisting of clover, grasses and weeds, as these are undoubtedly important factors in causing inside infestation.

It is estimated that the annual loss to cucumber men in the Boston market-garden district, due to red spider injury, amounts approximately to $150,000, or 10 per cent. of the whole crop.

Experimentation on the control of this mite attacking cucumbers gave no fumigant which could be used with safety to the foliage. Sulfur burned to form sulfur dioxide proved to be very effective in killing all stages of mites. Although this gas is deadly to plant life, its application as a fumigant to rid empty greenhouses of red spiders is extremely useful.

Many spray mixtures proved to be efficient in controlling actively feeding mites, but did not affect those in quiescent stages of development. For the control of all stages above the egg stage linseed oil emulsion proved to be the most satisfactory.

The control of the red spider may be accomplished by combining preventive and repressive measures.

Clean culture, or the eradication of weeds and plants which harbor mites during the winter period, either within or outside the greenhouse, is by far the most vital means of prevention in cucumber greenhouses.

Dispersion within the greenhouse may be hindered by destroying plants or parts of plants which harbor the initial infestation.

Applications of linseed oil emulsion at weekly intervals during the early life of the plant prove very effective if made with extreme care. At least three applications must be made for an efficient control.

By checking red spider infestation early in the season the producing period of the plants is lengthened approximately one month.

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BULLETIN No. 180 NOVEMBER, 1917

MASSACHUSETTS
AGRICULTURAL EXPERIMENT STATION

REPORT OF THE CRANBERRY SUBSTATION FOR 1916

By H. J. FRANKLIN

AND

OBSERVATIONS ON THE SPOILAGE OF CRANBERRIES DUE TO LACK OF PROPER VENTILATION

By C. L. SHEAR and NEIL E. STEVENS, Pathologists, and B. A. RUDOLPH, Scientific Assistant, Fruit-Disease Investigations, Bureau of Plant Industry, United States Department of Agriculture

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PUBLICATION OF THIS DOCUMENT
APPROVED BY THE
SUPERVISOR OF ADMINISTRATION.

BULLETIN No. 180.

DEPARTMENT OF AGRICULTURE.

REPORT OF THE CRANBERRY SUBSTATION FOR 1916.

BY H. J. FRANKLIN.

The investigations were mainly along the lines pursued in 1915. Many storage tests were conducted with the fruit, the description and results of which will be found particularly interesting.

Blueberry Culture.

A quarter of an acre was planted with six distinct strains of specially selected and bred swamp blueberry stock provided by the Bureau of Plant Industry of the United States Department of Agriculture. This was done under the direction of Prof. Frederick V. Coville, for the most part on August 31, about 375 plants being set out. The rows were 8 feet apart, and the plants were set at intervals of 4 feet in the row. Most of these plants made some growth during the fall, and seemed in good condition when winter began. A check row of unselected stock, taken from a neighboring swamp and planted on May 18, grew well during the summer. Many superior wild plants were selected when in fruit and marked for planting in 1917 as an additional check. It is hoped that the selected blueberry may prove a satisfactory substitute for cranberries on bogs where conditions make the growing of the latter fruit unprofitable. The commercial growing of the blueberry may also develop enough to compete with that of the cranberry in the cultivation of swamp soils, and thus provide a new industry for Massachusetts.

Weather Observations.

Weather observations were made as in previous years, thermometer readings and amounts of precipitation being telegraphed daily to the Boston office of the Weather Bureau during the periods of frost danger, and frost conditions being telephoned to growers on cold nights when asked for. The frost damage on the Cape this season was negligible.

Beginning with the second decade in May, wet weather prevailed more or less until about the 1st of August, culminating on July 24 in an all-day rain in which 4.20 inches fell at the station bog in twenty-four hours, this, because of the previous saturation of the ground, causing the streams to rise so much that the bogs located in considerable watersheds were generally flooded in spite of all efforts to keep the water down. It was estimated that over 1,000 acres of bearing bog on the Cape, either in or a little past the blooming period, were entirely submerged in this way.

The wet season provided unusual chances to study the effects of water on the blossoms and small berries. As a rule, the bogs bloomed heavily, and for a time a record-breaking crop was expected, but an unusually large proportion of the blossoms failed to set fruit. This failure took place especially among the under berries, for the crop turned out to be more "on top" than usual. Almost no berries were commonly found in thick clumps of vines where the blossoms had been very abundant, while in thin vines near by there was a fair amount of fruit. These conditions were general, though less so on bogs that either had no winter-flowage or had it taken off early. The wet weather evidently caused this failure of the set, though it is hard to say definitely how it did so. The rain may have prevented a proper fertilization of the flowers either by washing off the pollen or by preventing bees from working actively. Perhaps an unusual prevalence of fungous diseases induced by the excessive moisture blasted the blossoms.

It is the writer's present opinion, based on general observation and experience, that late holding of the winter-flowage so throws the blossoming period out of its normal season that the danger of its meeting unfavorable conditions for the setting of the fruit is usually considerably increased thereby.

That flooding when the berries are small is dangerous was shown by the effects observed on some bogs submerged for not over fifteen hours with the blooming period past and crop fully set. These bogs lost half their berries in spite of the cloudy weather that prevailed when the water was let off and for three days afterward. The largest of the berries injured under these circumstances were somewhat over a quarter of an inch in diameter. Many of the larger berries on some bogs, however, endured submergence two or three days without apparent injury.

Frost Protection.

In the fall of 1915 tests with new tobacco cloth, used in various ways on a bog with much moss under the vines, showed no considerable temperature advantage.

In the spring of 1916 this cloth was tried on a bog that was fairly well sanded and with only a little moss. Green registering thermometers were used in all the tests. Under one thickness of cloth spread on the vines they showed a higher minimum temperature than thermometers not covered, — by 3 degrees in some cases, though the usual difference was less than 2 degrees. Two thicknesses spread on the vines raised the minimum temperature from 3½ to 5 degrees, according to wind conditions, above that over the unprotected bog. One thickness supported on wires about hip high gave a medium advantage as compared with the single and double thicknesses spread on the vines.

In the fall these tests were continued on patches of unpicked vines on the station bog, and a maximum advantage of about 3 degrees with a single thickness and of 6 degrees with a double one was obtained. Moreover, this advantage continued after the vines had been covered with the cloth continuously day and night for nineteen days in a test begun September 25 and ended October 14.

The experience with this cloth justifies the following conclusions: —

(*a*) This protection is not satisfactory on bogs with much moss under the vines because of the reduced radiation on such bogs.

(*b*) Good secondhand cloth is so hard to get that its use is not practicable.

(*c*) One thickness of new cloth is not enough when spread on the vines.

(*d*) The difficulties and expense of wire supports prohibit their use.

(*e*) With two thicknesses spread on the vines, the protection is probably sufficient for most of the Cape bogs, and this seems the best way to use it. It is too bulky to handle easily on large areas, but it may be left on a bog continuously during quite a long cold period without reducing the protection afforded.

(*f*) It is better to protect with water if it can be done at reasonable expense.

Howes[1] berries that had undergone various low temperatures were picked and examined on November 15, as follows: —

1. Of 433 berries that had endured a temperature of 15½° F., 375 were entirely sound and 58 were soft. Eighteen of the latter showed unmistakably that they had decayed from fungous disease, leaving only 40, or 9.64 per cent., that could have been softened by frost; and perhaps even this figure should be reduced on account of fungous rot that could not be distinguished.

2. Of 442 berries that had undergone a temperature of 13½° F., 340 were sound and 102 soft. Of the latter, 26 showed that they had rotted because of fungous diseases, this leaving 76, or 18.27 per cent., that might have been frosted.

3. Of 444 berries exposed to a temperature of 9° F., 200 seemed entirely sound, 244 being soft. Twenty of the latter evidently had been softened by diseases, leaving only 224, or 52.83 per cent., that could have been hurt by frost.

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[1] This variety has been called "Late Howe" in previous reports of the cranberry substation. The writer is informed that it was first taken from the wild, and cultivated by the late James P. Howes of East Dennis, Howes being a common family name in that part of Cape Cod. As "Howe" is evidently a corruption, and as "late" is superfluous, all the varieties that have been called "Howe" being late, the name Howes is considered more appropriate and is therefore used in this report.

The temperatures here recorded were taken with Green minimum registering thermometers hung just over the vines bearing the berries. The fruit was well colored when it underwent these temperatures.

Several tests in both 1915 and 1916 showed that the temperature at which freezing begins among ripened Early Black or Howes cranberries is at or slightly above 22° F., no softening resulting from exposure to 23°.

The records of minimum temperatures at the station bog from 1911 to 1916, inclusive, show that no temperature low enough to harm well-colored berries appreciably occurred in any picking season of those six years.

The results of these investigations show that, for bogs in warm or average locations that are flooded by pumping, it is unprofitable in the long run to try to protect well-colored berries from frost, especially if the crop is light.

FUNGOUS DISEASES.

These investigations were conducted, as in previous years, in co-operation with the Bureau of Plant Industry of the United States Department of Agriculture, Dr. C. L. Shear and his assistant, Dr. Neil E. Stevens, visiting the Cape several times during the season, the latter spending several weeks at the station, and both giving sustained and aggressive attention to the more technical side of the work during a considerable period in the growing season and throughout the fall and early winter.

Table 1 is the season's record of the principal Bordeaux mixture spraying plots, experiments with which have been described in previous reports. None of these plots were treated this year, but the record is included here to show the effects on the 1916 crop of the spraying done in former years. Plots A, B, C, D and E were all sprayed in 1911, 1912 and 1913. The treatment was continued on plots A, B and D in 1914, but was stopped on C and E. It was further continued on A (entire plot) and on one-half of B and one-half of D in 1915. Plots 15 and "1913" were sprayed in 1913, 1914 and 1915. The whole of plot 15 has been treated with a complete mixture of commercial fertilizers for several years, as was also the middle part of A in 1913 and 1914. All the plots were picked with scoops as heretofore. Where two checks were taken they were laid out on opposite sides of the plot. The entire sections on which D and E are located, being small, were used as checks. The fruit used in the storage tests was stored, without separating, in quart cans with the covers on tight, but not sealed, the berries being taken by hand from different parts of the picking crates, all the crates picked being thus represented in the cans in most cases.

TABLE 1. — *Spraying Plots (Fungous Diseases). — Results of Spraying with Bordeaux Mixture in Previous Years shown by the 1916 Crop.*

PLOTS AND CHECKS.	Whether sprayed in 1915 or not.	Area (Square Rods).	Variety.	Date Picked, 1916.	Quantity of Fruit obtained (Bushels).	Quantity of Fruit per Square Rod (Bushels).	Quantity of Fruit placed in Storage Test (Quarts).	Period of Storage Test.	Percentage of Rotten and Partly Rotten Berries at End of Storage Test.
A (middle part),	Sprayed,	8	Howes,	Oct. 4	6.67	.83	9	Oct. 4 to Nov. 24	30.84
A (side strips),	Sprayed,	8	Howes,	Oct. 4	5.67	.71	7	Oct. 4 to Nov. 24	25.99
A (check 1),	Not sprayed,	4	Howes,	Oct. 4	5.33	1.33	8	Oct. 4 to Nov. 24	21.20
A (check 2),	Not sprayed,	4	Howes,	Oct. 4	4.60	1.15	8	Oct. 4 to Nov. 24	13.72
B (part sprayed in 1915),	Sprayed,	$7\frac{1}{16}$	McFarlin,	Oct. 7	5.67	.80	9	Oct. 7 to Nov. 23	32.55
B (part not sprayed in 1915),	Not sprayed,	$7\frac{1}{16}$	McFarlin,	Oct. 7	7.13	1.01	8	Oct. 7 to Nov. 23	23 55
B (check),	Not sprayed,	$13\frac{2}{3}$	McFarlin,	Oct. 7	12.83	.94	7	Oct. 7 to Nov. 24	23.27
C,	Not sprayed,	16	Howes,	Oct. 4	12.67	.79	8	Oct. 4 to Nov. 27	18.60
C (2 checks),	Not sprayed,	12	Howes,	Oct. 4	11.78	.98	8	Oct. 4 to Nov. 27	19.22
D,	One-half sprayed,	16	Early Black,	Sept. 29	12.83	.80	8	Sept. 29 to Dec. 2	51.68
D (check),	Not sprayed,	$40\frac{3}{10}$	Early Black,	Sept. 29	30.83	.77	8	Sept. 29 to Dec. 2	40.43
E,	Not sprayed,	16	Early Black,	Sept. 29	25.50	1.59	16	Sept. 29 to Dec. 4	44.42
E (check),	Not sprayed,	64	Early Black,	Sept. 29	63.25	.99	16	Sept. 29 to Dec. 4	40.58
"1913,"	Sprayed,	9	Howes,	Oct. 4	8.88	.98	8	Oct. 4 to Nov. 20	28.81
"1913" (check),	Not sprayed,	3	Howes,	Oct. 4	2.20	.73	5	Oct. 4 to Nov. 20	14.11
Sprayed half of fertilizer plot 15,	Sprayed,	4	Early Black,	Sept. 23	1.86	.47	6	Sept. 23 to Dec. 8	64.07
Other half of plot 15,	Not sprayed,	4	Early Black,	Sept. 23	2.67	.67	6	Sept. 23 to Dec. 8	62.12

TABLE 2. — *Spraying Plots (Fungous Diseases). — Results of Spraying with Bordeaux Mixture in Previous Years shown by the 1915 Crop.*

PLOTS AND CHECKS.	Whether sprayed in 1914 or not.	Area (Square Rods).	Variety.	Date picked, 1915.	Quantity of Fruit obtained (Bushels).	Quantity of Fruit per Square Rod (Bushels).	Quantity of Fruit placed in Storage Test (Bushels).[1]	Period of Storage Test.	Percentage of Rotten and Partly Rotten Berries at End of Storage Test.
B (part not sprayed in 1915),	Sprayed,	$7\frac{1}{16}$	McFarlin,	Oct. 13	3.07	.435	3	Oct. 13 to Jan. 7	19.05
B (check),	Not sprayed,	$13\frac{2}{3}$	McFarlin,	Oct. 13	10.83	.793	4	Oct. 13 to Jan. 7	12.60
D (part not sprayed in 1915),	Sprayed,	8	Early Black,	Sept. 22	5.00	.625	4	Sept. 22 to Jan. 5	33.41
D (check),	Not sprayed,	12	Early Black,	Sept. 22	13.75	1.146	4	Sept. 22 to Jan. 5	28.63

[1] Stored in bushel picking crates.

The table shows that as a rule the areas sprayed in 1915 were less productive in 1916 than their untreated checks, and that the fruit from these sprayed areas was inferior in keeping quality in all cases in 1916. In this connection the figures given for plots B and D in Table 2, taken from the last report of the substation (Bulletin No. 168, page 3), are of interest.

Judging by the results of the 1915 and 1916 storage tests given in Tables 1 and 2, the resistance of the plants to the attack of fungous diseases had been weakened by the injury caused by Bordeaux mixture described in previous reports.

Three plots, numbered, respectively, B. L. 1, B. L. 2 and B. L. 3, were sprayed with "Black-Leaf 40" used at the rate of 1 part to 400 parts of water, 2 pounds of resin fish-oil soap to 50 gallons being added to spread and stick the spray, on the dates and with the results shown in Table 3. These plots and their checks were all picked with scoops. The storage-test fruit was stored, without separating, in quart cans with covers on tight but not sealed, the berries being taken by hand from different parts of the picking crates, all the crates being thus represented.

The spray evidently did not much affect the quantity of fruit, and the storage tests showed no fungicidal value for it. This was not entirely a fair test, as all the sprayed areas had been treated with complete commercial fertilizer mixtures in 1915, but the impairment in keeping quality shown by the sprayed berries as compared with the check fruit was in all cases greater than that heretofore found by the writer to have resulted from the use of fertilizers. Did this spray have a harmful effect in this regard in some way?

Two plots, numbered A. L. 1 and A. L. 2, were sprayed with "Corona" arsenate of lead, used at the rate of 3 pounds to 50 gallons of water, on the dates and with the results shown in Table 4. These plots and their checks were picked with scoops, and the storage-test fruit was selected and stored in the same way as that of the "Black-Leaf 40" plots.

TABLE 3. — *Spraying Plots (Fungous Diseases). — Negative Results with "Black-Leaf 40" and Resin Fish-oil Soap.*

PLOTS AND CHECKS.	Variety.	Area (Square Rods).	Date of First Spraying.	Date of Second Spraying.	Date of Third Spraying.	Date Berries were picked.	Quantity of Fruit obtained (Bushels).	Quantity of Fruit Per Square Rod (Bushels).	Quantity of Fruit placed in Storage Test (Quarts).	Period of Storage Test.	Percentage of Rotten and Partly Rotten Berries found at End of Storage Test.
B. L. 1, ...	Early Black, . .	8	June 28	Aug. 1	Aug. 19	Sept. 23	4.00	.50	8	Sept. 23 to Dec. 2	57.17
B. L. 1 (check), . .	Early Black, . .	8	–	–	–	Sept. 23	7.50	.94	8	Sept. 23 to Dec. 2	40.89
B. L. 2, ...	Howes, ...	8	June 28	Aug. 1	Aug. 19	Oct. 5	8.17	1.02	8	Oct. 5 to Nov. 20	26.62
B. L. 2 (check), . .	Howes, ...	6	–	–	–	Oct. 5	6.50	1.08	8	Oct. 5 to Nov. 20	19.69
B. L. 3, ...	Early Black, . .	4	June 28	Aug. 1	Aug. 19	Sept. 26	3.33	.83	6	Sept. 26 to Nov. 27	53.70
B. L. 3 (check), . .	Early Black, . .	4	–	–	–	Sept. 26	3.17	.79	6	Sept. 26 to Nov. 27	38.45

TABLE 4. — *Spraying Plots (Fungous Diseases). — Results with Arsenate of Lead.*

PLOTS AND CHECKS.	Variety.	Area (Square Rods).	Date of First Spraying.	Date of Second Spraying.	Date of Third Spraying.	Date Berries were picked.	Quantity of Fruit obtained (Bushels).	Quantity of Fruit Per Square Rod (Bushels).	Quantity of Fruit placed in Storage Test (Quarts).	Period of Storage Test.	Percentage of Rotten and Partly Rotten Berries found at End of Storage Test.
Plot A. L. 1,	Early Black,	9	June 28	Aug. 1	Aug. 19	Sept. 25	11.00	1.22	8	Sept. 25 to Nov. 25	30.04
A. L. 1 (check 1),	Early Black,	6	-	-	-	Sept. 25	6.67	1.11	8	Sept. 25 to Nov. 25	36.02
A. L. 1 (check 2),	Early Black,	9	-	-	-	Sept. 25	9.80	1.09	8	Sept. 25 to Nov. 25	33.70
Plot A. L. 2,	Early Black,	9	June 28	Aug. 1	Aug. 19	Sept. 21	9.40	1.04	14	Sept. 23 to Nov. 29	35.30
A. L. 2 (check 1),	Early Black,	6	-	-	-	Sept. 21	6.10	1.02	12	Sept. 23 to Nov. 29	40.92
A. L. 2 (check 2),	Early Black,	6	-	-	-	Sept. 21	6.00	1.00	12	Sept. 23 to Nov. 29	44.13

The table shows little if any increase in yield from this treatment. The berries of both plots, however, showed a rather remarkable improvement in keeping quality over the fruit of the unsprayed checks, especially when the small number and lateness of the treatments are considered. In both cases the two checks were laid out on opposite sides of the plot.

While these tests are not enough to prove a fungicidal value for arsenate of lead in the treatment of any cranberry disease, their results are suggestive. It should be recalled in this connection that this insecticide is a well-proved treatment for apple scab. Dr. Shear found that most of the rot in Early Black berries produced by the station bog this year was due to anthracnose, a disease caused by a fungus known to science as *Glomerella rufomaculans vaccinii* Shear.

To test further the possibility of controlling fungous diseases by putting copper sulfate in the flowage, experimental flooding sections 23 and 27 of the station bog were treated, as in 1915, with this chemical in the June reflow at the rate of 1 part to 50,000 parts of water (1 pound in 6,250 gallons). The treatment was applied June 14 after the sections had been completely submerged for twelve hours, and the water was then held thirty hours longer. Even distribution of the chemical was obtained by pulling it around in a sack in the water as it dissolved. The areas thus treated showed no definite advantage either in the quantity or the keeping quality of the fruit, as compared with the untreated flooding sections adjoining them.

It seemed to be the general opinion among the Cape growers that cranberries as a rule kept distinctly better than usual this year in spite of the wet weather in the first half of the growing season.

The hypertrophy of the tender vegetative shoots, frequently called "false blossom" by the growers, and for which Dr. Shear has suggested the name "rose bloom," was unusually abundant on the station bog this season. It has been thought that the moisture conditions attending late holding of the winter-flowage, excessive reflowage, deficient drainage or excessive and continual rainfall greatly favor the development of the fungus (*Exobasidium oxycocci* Rostr.) which causes this disease. The late holding of the winter-flowage in both 1915 and 1916 in conjunction with the very rainy season may, therefore, partly explain its prevalence on the bog.

An unusual occurrence with this disease was its attack on the blossoms, its effects hitherto, so far as observed, being confined to the leafy shoots. As estimated from 3 to 4 per cent. of the Howes blossoms on the station bog were conspicuously deformed by the disease between July 20 and August 1, when this effect was most marked. An occasional Early Black flower was also affected. A few of the small berries were somewhat swollen and discolored by the disease, and covered with the spores of the fungus. That this attack on the flowers and small berries probably was due mainly to the prolonged spell of wet weather was shown by the prompt disappearance of the disease on both blossoms and vines when the wet season ended.

Dr. Shear has recently published a valuable paper [1] on the false blossom disease that does so much harm in Wisconsin and has heretofore been reported [2] as having been introduced into Massachusetts and New Jersey.

STORAGE TESTS.

The description of all these experiments that seemed to give results of much interest are arranged in the groups listed below. Those in group No. 1 were planned by the writer and conducted by Prof. F. W. Morse, research chemist of the Massachusetts Agricultural Experiment Station. Group No. 2 was planned and carried out by Dr. N. E. Stevens. Nos. 4, 6 (*c*), 7, 10 and 13 were planned and conducted by the writer. Nos. 3, 5, 6 (*a*) and (*b*), 8 and 11 were planned by Drs. Shear and Stevens, and were carried out by them co-operatively with the writer. No. 12 was planned and conducted co-operatively by Dr. Stevens and the writer.

Some of the tests were conducted with berries in quart cans, with covers on tight but not sealed, and others with fruit in bushel picking crates stored in carefully arranged stacks. A comparison of the percentages of decay found in the crates and the cans shows strikingly the harmful effect of the lack of ventilation in the latter, this being so great that it perhaps invalidates the results of the can tests.

In all the tests, except those of groups 1, 2, 9, 11 and 13, the fruit was examined by cup samples by the screeners employed at the station during the fall, under the writer's supervision, the inspector's cup of the New England Cranberry Sales Company being used for sampling. The Sales Company's hand grader was used to facilitate the work. All the berries stored in cans were included in samples and examined.

The "nine-sample" method was largely used in examining the crates. In this method nine samples from each crate were counted, one being taken from the top or surface berries at each end; one from the surface berries at the middle; one from the berries halfway between the top and bottom at each end; one from the very center; one from the very bottom at each end; and one from the bottom at the middle.

The "seven-sample" method was used in examining some of the crated berries, and the writer thinks this method is as satisfactory as any likely to be devised for determining the condition of berries thus stored, considerable defects in the other methods so far employed having been discovered. In this method seven samples from each crate were examined, one being taken from the surface berries of each half of the crate halfway between the middle and the end; one from each half of the crate halfway between the top and the bottom and halfway between the center and the end; one from the very center; and one from the very bottom of each half of the crate halfway between the middle and end.

All the tests except those of the first, second, eleventh and thirteenth groups were conducted in the basement of the station screenhouse, this having a floor and walls of concrete and providing fairly even temperatures.

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[1] False Blossom of the Cultivated Cranberry, Bul. No. 444, U. S. Dept. Agr., November, 1916.

[2] Bul. No. 160, Mass. Agr. Expt. Sta., 1915, pp. 99 and 100, and Bul. No. 168, Mass. Agr. Expt. Sta., 1916, p. 5.

A Friez hygro-thermograph provided by the Bureau of Plant Industry and kept in the storage room during most of the period when the tests were in progress gave the following temperature and humidity records: —

Between September 29 and October 1 the temperature fell from 77° F. to 60° F. Between October 1 and October 5 it ranged between 61° and 54°. As the mainspring of the hygro-thermograph clock broke on October 5 the records were discontinued until October 25. Beginning on that date the ranges in temperature by weeks were as follows: October 25 to November 1, from 57° to 53°; November 1 to November 8, from 53° to 47°; November 8 to November 15, from 51° to 44°; November 15 to November 22, from 47° to 38°; November 22 to November 29, from 51° to 38°; November 29 to December 6, from 51° to 43°; December 6 to December 13, from 49° to 40°; December 13 to December 20, from 42° to 29°; December 20 to December 24, from 41° to 34°.

Between September 29 and October 5 the relative humidity ranged from 95 to 59 per cent., and was subject to much influence from frequent opening of the storage room. Beginning with October 25 the ranges in relative humidity by weeks were as follows: October 25 to November 1, from 85 to 72 per cent.; November 1 to November 8, from 85 to 69 per cent.; November 8 to November 15, from 85 to 60 per cent.; November 15 to November 22, from 73 to 60 per cent.; November 22 to November 29, from 86 to 53 per cent.; November 29 to December 6, from 75 to 46 per cent.; December 6 to December 13, from 71 to 50 per cent.; December 13 to December 20, from 72 to 53 per cent.; December 20 to December 24, from 79 to 55 per cent.

The storage room was kept tightly closed from October 25 to December 24, except as the making of observations made entrance necessary. In spite of this, the fluctuations in relative humidity were marked and rapid, it evidently being influenced much more by outside weather conditions than by the stored berries.

The storage tests conducted fall conveniently into groups, as follows: —

1. *Weight Shrinkage of Sound Cranberries in Storage is due largely, if not entirely, to Losses Incidental to the Process of Respiration, not to Loss of Water by Evaporation.* — To determine this, Professor Morse weighed and analyzed different lots of Howes berries, obtained from the same source, on various dates and with results as shown in Table 5. Professor Morse provides the following data concerning this work: —

> The cranberries were received at the chemical laboratory the first week in December.
>
> On December 8, eight approximately equal lots of carefully selected sound berries were weighed into glass jars. The mouths of the jars were covered with a thin filter paper held in place by rubber bands, and they were inverted in a slat-bottomed box and placed in a cool closet, the temperature of which ranged between 35° and 60° F.

The berries were put into jars to prevent too free circulation of air, and the jars were inverted to permit the heavy carbon dioxide gas to diffuse through the filter paper and escape. Beginning December 16, and thereafter at fortnightly intervals, a jar was removed from the closet. The contents were weighed, rotten berries were picked out and weighed, and a sample of sound berries was used for an estimation of the actual dry matter in the fruits.

Each successive date showed more and more decayed fruit, and on March 17 the last two jars were removed together, because it seemed useless to continue the experiment further.

TABLE 5. — *Analyses of Cranberries. — Dry-Matter Content at End of Various Periods of Storage.*

LOT.	Weight December 8 (Grams).	Date reweighed and analyzed.	Weight after Keeping (Grams).	Loss (Per Cent.).	Dry Matter in Sound Fruit (Per Cent.).	Weight of Rotten Fruit (Grams).
A,	153.4	Dec. 16	152.7	-	12.12	-
B,	156.8	Jan. 2	154.9	1.2	12.14	25.4
C,	158.1	Jan. 16	154.7	2.1	11.87	44.7
D,	158.5	Feb. 2	153.8	2.9	11.94	67.6
E,	158.6	Feb. 16	152.8	3.6	11.94	70.0
F,	161.3	Mar. 3	154.5	4.2	12.02	85.3
G,	161.7	Mar. 17	153.2	5.2	11.82	92.7
H,	164.9	Mar. 17	157.0	4.7	-	89.0

Professor Morse remarks concerning these results as follows: —

The loss in weight is due partly to the shrinkage in the decayed berries, which is caused by decomposition and evaporation.

The sound fruit showed a small but positive diminution in dry matter after the first fortnight, but not an increasing one. Only by weighing individual berries could it be positively determined how much the cranberry loses in weight while yet sound. The small shrinkage in proportion of dry matter indicates that respiratory destruction occurs, as in apples, pears, etc.

2. *Temperature of Berries when picked.* — These investigations were not storage tests, strictly speaking, but as their results bear on the matter of cooling previous to storage they are included here.

Air temperatures and temperatures taken among berries in crates as soon as they were filled by pickers were recorded by Dr. Stevens, as shown in Table 6.

TABLE 6. — *Temperatures of Cranberries when picked compared with Air Temperatures.*

Bog where Temperatures were taken.	Date, and Condition of the Weather when the Temperatures were taken.	Variety of Berries.	Hour of Day Temperatures were taken.	Air Temperature in Shade.	Temperature of Berries when picked (taken at Center of Picking Crate).
Station, . . .	Oct. 3, clear and sunny.	Howes, . .	7.30 A.M.	49° F.	49° F.
			8.30 A.M.	60° F.	62° F.
			9.00 A.M.	62° F.	64° F.
			9.20 A.M.	62° F.	68° F.
			9.40 A.M.	63° F.	75° F.
			10.40 A.M.	70° F.	79° F.
			11.00 A.M.	70° F.	79° F.
			11.30 A.M.	71° F.	81° F.
			11.55 A.M.	71° F.	81° F.
			2.15 P.M.	70° F.	75° F.
			2.55 P.M.	70° F.	74° F.
			3.00 P.M.	70° F.	73° F.
Station, . . .	Sept. 20, bright sun.	Early Black, .	11.10 A.M.	66° F.	81° F.
			3.30 P.M.	64° F.	70° F.
			4.30 P.M.	61° F.	65° F.
Station, . . .	Sept. 18, . .	Early Black, .	11.15 A.M.	75° F.	84° F.
			12.45 P.M.	74° F.	85° F.
			1.30 P.M.	74° F.	82° F.
			3.40 P.M.	67° F.	72° F.
Station, . . .	Sept. 23, . .	Early Black, .	9.30 A.M.	75° F.	80° F.
			11.30 A.M.	76° F.	87° F.
			11.45 A.M.	76° F.	89° F.
Old Colony bog, South Dennis, Mass.	Sept. 22, . .	Early Black, .	11.30 A.M.	73° F.	86° F.
			11.45 A.M.	73° F.	89° F.
			3.00 P.M.	73° F.	86° F.

These records show that under ordinary harvesting conditions cranberries attain high temperatures on the vines. It has been found that with the crate containers commonly used these temperatures do not change rapidly unless the berries are placed in very cool storage after they are picked.

The difference between the temperature of the air and that of the berries when picked is greatest when the sun is highest, and is least early in the morning and late in the afternoon. Tests with green and ripe berries in small glass containers failed to show any appreciable difference between berries of different colors.

3. *Hand-picking* v. *Scoop-picking as affecting Keeping Quality.* — Two series of tests come under this head, as follows: —

(*a*) Twelve parallel and adjacent strips of Early Black vines, each approximately 50 feet long by 5½ feet wide, were picked in alternation with scoops and by hand on September 18, a single full crate being obtained from each strip. In the hand-picking, each man was allowed to follow his own method, and a great difference was observed in the ways in which they did the work, some tearing the berries from the vines with their fingers used much like scoop-teeth, and some picking individual berries much as strawberries are commonly gathered. Six of the crates, three hand-picked and three scoop-picked, were placed in the storage room at once, the rest being left in the sun on the bog for several hours. Test No. 1 of Table 7 completes the record of these tests.

(*b*) Twelve crates of Howes berries, picked by hand and with scoops in alternation, as in the first series of tests, from an equal number of narrow parallel and adjacent strips of vines, were handled as indicated in test No. 2, of Table 7.

The averages of the table show that the scooped berries kept slightly better than the hand-picked ones in both series of tests. All this fruit was stored as it came from the bog without cleaning in any way. The crates were examined by the "nine-sample" method in determining the rot percentages.

TABLE 7. — *Hand-picking v. Scoop-picking as affecting Cranberry Keeping, and Effect on Keeping of leaving Berries in the Sun instead of housing them promptly.*

Test No. 1, Early Black Variety.

LOT No.	Method and Date of picking.	Quantity of Fruit (Bushels).	Housed at once or left on Bog in Sun.	Crate No.	Hour of Day picked.	Temperature of Berries when picked.	Hour of Day housed.	Temperature when housed.	Period of Storage Test.	Percentage of Rotten and Partly Rotten Berries found at End of Storage Test.	Averages of Percentages of Rotten and Partly Rotten Berries.	Averages of Percentages.
A, . .	By hand, Sept. 18, .	6	Housed at once, .	1	1.45 P.M.	82° F.	2.00 P.M.	82° F.	Sept. 18 to Dec. 14	27.60	25.66	27.05
				2	2.30 P.M.	78° F.	2.45 P.M.	78° F.	Sept. 18 to Dec. 14	29.84		
				3	3.15 P.M.	72° F.	3.30 P.M.	72° F.	Sept. 18 to Dec. 11	19.54		
			Left on bog, .	4	11.15 A.M.	84° F.	4.00 P.M.	81° F.	Sept. 18 to Dec. 14	28.34	28.43	
				5	11.30 A.M.	84° F.	4.00 P.M.	81° F.	Sept. 18 to Dec. 14	28.34		
				6	1.15 P.M.	82° F.	4.00 P.M.	81° F.	Sept. 18 to Dec. 14	28.60		
B, . .	With scoops, Sept. 18, .	6	Housed at once, .	1	2.00 P.M.	82° F.	2.15 P.M.	82° F.	Sept. 18 to Dec. 14	25.61	23.83	25.98
				2	2.30 P.M.	78° F.	2.45 P.M.	78° F.	Sept. 18 to Dec. 11	22.57		
				3	3.45 P.M.	72° F.	4.00 P.M.	72° F.	Sept. 18 to Dec. 14	23.32		
			Left on bog, .	4	11.10 A.M.	84° F.	4.00 P.M.	81° F.	Sept. 18 to Dec. 14	27.38	28.14	
				5	11.45 A.M.	85° F.	4.00 P.M.	81° F.	Sept. 18 to Dec. 14	28.55		
				6	1.30 P.M.	82° F.	4.00 P.M.	81° F.	Sept. 18 to Dec. 14	28.50		

Test No. 2, Howes Variety.

LOT No.	Method and Date of picking.	Quantity of Fruit (Bushels).	Housed at once or left on Bog in Sun.	Crate No.	Hour of Day picked.	Temperature of Berries when picked.	Hour of Day housed.	Temperature when housed.	Period of Storage Test.	Percentage of Rotten and Partly Rotten Berries found at End of Storage Test.	Averages of Percentages of Rotten and Partly Rotten Berries.	Averages of Percentages.
C, . .	By hand, Oct. 3, . .	6	Housed at once, .	1	11.15 A.M.	81° F.	11.30 A.M.	81° F.	Oct. 3 to Dec. 14	14.93	14.99	13.24
				2	11.45 A.M.	81° F.	12.00 M.	81° F.	Oct. 3 to Dec. 14	14.67		
				3	2.35 P.M.	74° F.	3.00 P.M.	74° F.	Oct. 3 to Dec. 14	15.38		
			Left on bog, .	4	10.30 A.M.	79° F.	4.00 P.M.	76° F.	Oct. 3 to Dec. 14	8.21	11.48	
				5	10.45 A.M.	79° F.	4.00 P.M.	76° F.	Oct. 3 to Dec. 14	9.86		
				6	2.00 P.M.	75° F.	4.00 P.M.	75° F.	Oct. 3 to Dec. 14	16.37		
D, . .	With scoops, Oct. 3, .	6	Housed at once, .	1	11.25 A.M.	81° F.	11.30 A.M.	81° F.	Oct. 3 to Dec. 14	12.06	11.25	10.98
				2	11.55 A.M.	81° F.	12.00 M.	81° F.	Oct. 3 to Dec. 14	12.05		
				3	2.45 P.M.	73° F.	3.00 P.M.	73° F.	Oct. 3 to Dec. 14	9.64		
			Left on bog, .	4	10.35 A.M.	79° F.	4.00 P.M.	76° F.	Oct. 3 to Dec. 14	11.16	10.71	
				5	10.55 A.M.	79° F.	4.00 P.M.	76° F.	Oct. 3 to Dec. 14	10.70		
				6	2.10 P.M.	76° F.	4.00 P.M.	75° F.	Oct. 3 to Dec. 14	10.26		

In partial confirmation of the evidence presented above, that scoop-picking is not especially harmful to the keeping quality of cranberries, a recital of the experience with 14 bushel crates of Early Black berries picked with scoops in two different ways from narrow alternating parallel and adjacent strips of vines is here included. In picking seven of these crates the scoops were allowed to fill to a considerable extent as usual before emptying, the berries churning back and forth as they accumulated. With the other boxes the berries were not allowed to collect as they were picked, but were poured out of the scoops after each pull through the vines. The results of the storage of this fruit are shown in Table 8. The churned berries kept as well as the unchurned. The crates were examined by the "nine-sample" method.

TABLE 8. — *Picking Test. — The Scoop-churning of Berries during the Process of Picking does not materially affect Keeping Quality.*

HOW BERRIES WERE SCOOPED.	Date picked and stored.	Quantity stored (Bushels).	How stored.	Date examined to determine Rot Percentage.	Percentage of Rotten and Partly Rotten Berries found at End of Test.
With churning, .	Oct. 8	7	Unseparated, in picking crates, .	Dec. 19	29.51
Without churning, .	Oct. 8	7	Unseparated, in picking crates, .	Dec. 19	29.64

4. *Relative Keeping Quality of the Upper and Under Berries of the Vines.* — The three tests to determine this were carried out as indicated by Table 9, the results showing rather conclusively that the berries most exposed to sun and wind during their growth are considerably better keepers than those produced under the protection of the vines. Moreover, the top berries were much more highly colored and averaged considerably larger in size than the others when picked.

These berries were all picked by hand under the supervision of the writer, who did much of the work himself. They were stored in quart cans.

TABLE 9. — *Upper and Under Berries compared as to Keeping Quality.*

Test No.	VARIETY.	Berries.	Date picked.	Quantity placed in Storage Test (Quarts).	Period of Storage Test.	Percentage of Rotten and Partly Rotten Berries found at End of Storage Test.
1, .	Early Black, .	Only sound upper berries.	Sept. 30	6	Sept. 30 to Dec. 2	31.55
		Only sound under berries.	Sept. 30	6	Sept. 30 to Dec. 2	38.83
2, .	Early Black, .	Only sound upper berries.	Oct. 6	14	Oct. 6 to Nov. 20	28.74
		Only sound under berries.	Oct. 6	12	Oct. 6 to Nov. 21	37.93
3, .	Howes, . .	Only sound upper berries.	Oct. 13	6	Oct. 13 to Dec. 9	15.49
		Only sound under berries.	Oct. 13	6	Oct. 13 to Dec. 9	18.44

It seems to be the general experience with Cape Cod bogs that late holding of the winter-flowage improves the keeping quality of the berries. As the writer has observed that late holding of the water frequently reduces the quantity of under berries as compared with the amount of fruit produced in the tops of the vines, the results of these tests may partly explain this improvement. They also suggest that the generally recognized good comparative keeping quality of the 1916 crop may have been due largely to the very general failure of the under berries to set in their usual abundance.

The deeper the scoops are run through the vines in picking, the greater the proportion of under berries that are gathered and the greater, also, the quantity of unattached cranberry leaves and sand that gets mixed with the fruit. On account of the inferior keeping quality of the under berries here shown, and because of the harm done by admixtures of loose leaves proved by tests described below (No. 7, page 206), the desirability of closely scooping berries that are to be stored long is rendered doubtful.

5. *Housing promptly* v. *Leaving Crates of Berries in the Sun on the Bog, as affecting Cranberry Keeping.* — Eight series of tests were carried out in this connection, four with Early Black and four with Howes fruit. Four of these were conducted in connection with the picking experiments described above (No. 3, page 197), Table 7 showing their arrangement and results. Dr. Stevens took all the temperatures given in this table with chemical thermometers, their bulbs being plunged to the centers of the crates. At 8 A.M., September 19, the temperatures of the twelve boxes of Early Black berries ranged from 68° to 70° F., and at 8 A.M., September 20, they ranged from 61° to 62°, from which there was little change for several days after.

The records in Table 7 show that as a rule the temperature of berries left in crates on the bog exposed to the sun for several hours did not change more than 3 degrees. The temperatures of some of these crates were taken every thirty minutes from the time they were picked until they were housed, almost no variation being discovered until very near the latter time. The averages of percentages given in the table indicate that the Early Black berries housed at once kept somewhat better than those left on the bog, whereas these results with the Howes fruit were reversed. This difference in the storage of the two varieties corresponded with the difference in the average temperatures of the different lots when housed, the Early Black berries housed at once averaging to have lower temperatures when placed in storage than did those left on the bog, whereas the Howes fruit housed at once had a somewhat higher average temperature when stored than did that left on the bog.

The four other experiments under this head were carried out in connection with some of the tests of the effect of wetness on cranberry keeping described below (No. 6 (*a*), page 201), Table 10 exhibiting their arrangement and results. As in the first four series of tests, Dr. Stevens took all the temperatures with chemical thermometers at the centers of the crates. It was partly cloudy all day the day that the Early Black berries used in these tests were picked. The averages of percentages in the table show that with both varieties the wet berries kept better after having been left on the bog, whereas the dry ones kept better when housed at once.

On the whole, the results of these tests were inconclusive, though they failed to show much harm to the keeping quality resulting from leaving the crated fruit on the bog for several hours under ordinary harvesting and storage conditions.

6. *Wet and Dry Cranberries compared as to Keeping.* — Three series of tests come under this head, as follows: —

(*a*) An area 60 feet square laid out on Early Black vines on the station bog was divided into equal parts by lines running diagonally between the corners. Two of the opposite triangles thus formed were scooped while the berries were wet with dew, the other two being left until they were dry. The ways in which these berries were tested and the results obtained are shown in test No. 1 of Table 10.

(*b*) An area 100 by 30 feet laid out on Howes vines on the station bog was divided into triangles by diagonal lines between the corners. Two opposite triangles were picked with scoops while the vines were more or less wet with dew, and the other two when they were dry. The manner of testing this fruit and the results obtained with it are shown in test No. 2 of Table 10.

TABLE 10. — *Effect of Wetness and of leaving Berries in the Sun on Cranberry Keeping.*

Test No. 1, Early Black Variety.

METHOD AND DATE OF PICKING.	Lot No.	Quantity of Fruit (Bushels).	In What Condition picked.	Housed at once or left on Bog in Sun.	Crate No.	Hour of Day picked.	Temperature of Berrries when picked.	Hour of Day housed.	Temperature when housed.	Period of Storage Test.	Percentage of Rotten and Partly Rotten Berries found at End of Storage Test.	Averages of Percentages of Rotten and Partly Rotten Berries.	Averages of Percentages.
With scoops, Sept. 20,	A,	6	Wet,	Housed at once, .	1	10.15 A.M.	62° F.	10.45 A.M.	62° F.	Sept. 20 to Dec. 16	36.10	36.43	36.19
					2	10.15 A.M.	62° F.	10.45 A.M.	62° F.	Sept. 20 to Dec. 16	37.34		
					3	10.30 A.M.	66° F.	10.45 A.M.	66° F.	Sept. 20 to Dec. 15	35.85		
				Left on bog, .	4	10.00 A.M.	59° F.	3.00 P.M.	62° F.	Sept. 20 to Dec. 16	37.42	35.94	
					5	10.00 A.M.	59° F.	3.00 P.M.	62° F.	Sept. 20 to Dec. 16	34.54		
					6	10.30 A.M.	66° F.	3.00 P.M.	66° F.	Sept. 20 to Dec. 15	35.86		
	B,	6	Dry,	Housed at once, .	1	11.30 A.M.	81° F.	11.45 A.M.	81° F.	Sept. 20 to Dec. 16	16.82	22.60	23.05
					2	11.30 A.M.	81° F.	11.45 A.M.	81° F.	Sept. 20 to Dec. 16	25.66		
					3	11.30 A.M.	81° F.	11.45 A.M.	81° F.	Sept. 20 to Dec. 15	25.33		
				Left on bog, .	4	11.30 A.M.	81° F.	At sunset	79° F.	Sept. 20 to Dec. 16	21.63	23.50	
					5	11.30 A.M.	81° F.	At sunset	79° F.	Sept. 20 to Dec. 16	22.26		
					6	11.30 A.M.	81° F.	At sunset	79° F.	Sept. 20 to Dec. 16	26.61		

Test No. 2, Howes Variety.

METHOD AND DATE OF PICKING.	Lot No.	Quantity of Fruit (Bushels).	In What Condition picked.	Housed at once or left on Bog in Sun.	Crate No.	Hour of Day picked.	Temperature of Berrries when picked.	Hour of Day housed.	Temperature when housed.	Period of Storage Test.	Percentage of Rotten and Partly Rotten Berries found at End of Storage Test.	Averages of Percentages of Rotten and Partly Rotten Berries.	Averages of Percentages.
With scoops, Oct. 3, .	C,	6	Wet,	Housed at once, .	1	9.25 A.M.	69° F.	9.30 A.M.	69° F.	Oct. 3 to Dec. 14	13.47	15.08	13.50
					2	9.00 A.M.	63° F.	9.15 A.M.	63° F.	Oct. 3 to Dec. 15	14.38		
					3	9.00 A.M.	63° F.	9.15 A.M.	63° F.	Oct. 3 to Dec. 15	17.38		
				Left on bog, .	4	9.20 A.M.	68° F.	4.00 P.M.	73° F.	Oct. 3 to Dec. 15	9.63	11.92	
					5	9.15 A.M.	66° F.	4.00 P.M.	73° F.	Oct. 3 to Dec. 16	13.07		
					6	9.00 A.M.	64° F.	4.00 P.M.	73° F.	Oct. 3 to Dec. 15	13.06		
	D,	6	Dry,	Housed at once, .	1	10.00 A.M.	77° F.	10.00 A.M.	77° F.	Oct. 3 to Dec. 15	9.88	11.32	12.54
					2	10.00 A.M.	77° F.	10.00 A.M.	77° F.	Oct. 3 to Dec. 14	12.68		
					3	10.00 A.M.	77° F.	10.00 A.M.	77° F.	Oct. 3 to Dec. 15	11.40		
				Left on bog, .	4	10.00 A.M.	77° F.	4.00 P.M.	74° F.	Oct. 3 to Dec. 16	10.40	13.75	
					5	10.00 A.M.	77° F.	4.00 P.M.	74° F.	Oct. 3 to Dec. 15	15.29		
					6	10.00 A.M.	77° F.	4.00 P.M.	74° F.	Oct. 3 to Dec. 14	15.57		

The averages of percentages in the table show that the berries stored wet rotted more than those stored dry in both series of tests. The wet berries in the second series were more nearly dry when picked than were those of the first series, this apparently accounting for the smaller difference in the average amounts of rot that developed in the two lots of Howes fruit. The wet berries left on the bog were perhaps dried a good deal, as compared with those housed at once, by the high temperatures and free circulation of the open air, this perhaps explaining their better keeping.

All the berries in these tests were stored in bushel picking crates as they came from the bog, without cleaning in any way. Their rot percentages were determined by the "nine-sample" method.

(*c*) The two tests in the third series are fully explained by Table 11. The wet berries in these tests were considerably wetter than those in either of the first two series, the moisture being that of a very heavy dew. All the crates were stored as soon as the berries were picked. The temperatures given in the table were taken by the writer when the fruit was housed, chemical thermometers being plunged to the centers of the crates. When the four crates picked on October 4 were stored, the temperature of those picked the night before was 50° F. The temperatures of the wet and dry picked berries did not become equalized in storage until some time during the night of October 6 and 7.

All this fruit was stored without cleaning. The crates were examined by the "nine-sample" method.

TABLE 11. — *Effect of Wetness on Cranberry Keeping.*

Test No.	Lot No.	VARIETY.	Date picked.	Hour of Day picked.	How picked.	In what Condition picked.	Temperature at which picked.	Quantity of Fruit (Bushels).	How stored.	Period of Storage Test.	Percentage of Rotten and Partly Rotten Berries found at End of Storage Test.
1,	A,	Early Black, . . .	Oct. 3	9 to 10 P.M.	Scooped.	Very wet.	38° F.	2	In picking crates, . .	Oct. 3 to Dec. 16	46.81
	AA,	Early Black, . . .	Oct. 4	12 to 1 P.M.	Scooped.	Dry.	73° F.	2	In picking crates, . .	Oct. 4 to Dec. 16	24.31
2,	B,	Howes, ...	Oct. 3	9 to 10 P.M.	Scooped.	Very wet.	38° F.	2	In picking crates, . .	Oct. 3 to Dec. 16	41.47
	BB,	Howes, ...	Oct. 4	12 to 1 P.M.	Scooped.	Dry.	74° F.	2	In picking crates, . .	Oct. 4 to Dec. 16	17.68

TABLE 12. — *Effect of an Admixture of Cranberry Leaves on the Keeping of the Berries.*

Test No.	VARIETY OF BERRIES TESTED.	Date Berries were picked.	Period of Storage.	Lot No.	Quantity of Fruit placed in Storage (Bushels).	In what Condition stored.	Percentage of Rotten and Partly Rotten Berries found at End of Storage Test.
1,	Early Black,	Sept. 20	Sept. 20 to Dec. 18,	1	4	With neither vines nor leaves,[1]	33.74
				2	4	With vines and leaves attached,[2]	30.62
2,	Early Black,	Sept. 29	Sept. 29 to Dec. 18,	1	3	With neither vines nor leaves,	19.70
				2	3	With vines and leaves attached,	16.84
				3	3	With vines stripped of leaves,[3]	18.02
				4	3	With leaves only,[4]	25.17
3,	Howes,	Oct. 5	Oct. 5 to Dec. 19,	1	3	With neither vines nor leaves,	11.21
				2	3	With vines and leaves attached,	11.01
				3	3	With vines stripped of leaves,	9.96
				4	1	With leaves only,	14.83
4,	Howes,	Oct. 7	Oct. 7 to Dec. 18,	1	3	With neither vines nor leaves,	14.04
				2	3	With vines stripped of leaves,	12.56
				3	3	With leaves only,	20.95

[1] Fairly well cleaned of vines by hand.

[2] No vines taken out, but left just as they were poured out of the scoops.

[3] The bare cranberry vines, with the leaves removed, mixed in with the berries in considerable quantity.

[4] About a quart of green cranberry leaves stripped from the vines and mixed with the berries in each crate.

The table shows that the results of this test strongly confirmed those of the first two, giving striking evidence of the harmful effect of excessive moisture among cranberries in storage.

7. *Effects of Admixtures of Vines and Leaves on Cranberry Keeping.* — The four series of tests in this connection were carried out as shown in Table 12. The fruit was picked with scoops and was stored in bushel picking crates. The crates were examined by the "nine-sample" method.

The table shows that these tests gave convincing evidence of the harmful effect of an admixture of unattached cranberry leaves in the storage of the fruit. They also indicated that the berries keep as well with the admixture of vines and leaves attached, commonly obtained in scooping, as any way. The entire removal of the vines and leaves, aside from the injury done in the process, however, seems to do no harm.

8. *Berries separated with Hayden and with White Machines and Berries screened without separating compared as to Keeping Quality.* — The berries used in these two series of tests were handled throughout in the same way. The three lots of fruit in each series came from the same source, individual crates of berries as they came from the bog being divided as evenly as possible into three separate parts by successive pourings into barrels to produce them, care being taken to handle the berries of the different lots as nearly alike as possible. As there was no White separator in working order in East Wareham at the time, all this fruit was carted in open barrels in a farm wagon (without springs) to the Makepeace screenhouse at Wareham, two of the lots of each series being there run through Hayden and White separators, respectively. The berries were received into barrels from both the Hayden and the White machines, those of the first box (the "good" box) also being used in the test in the case of the former. The berries of all the lots were carted back in the open barrels to the station screenhouse, where they were hand-screened, the fruit in all cases being received into picking crates placed close to the mouths of the screens and being stored in those crates. The arrangement and results of these tests are shown in Table 13. The "nine-sample" method was used in examining the crates.

TABLE 13. — *Injury to Keeping Quality of Cranberries caused in Separating. — Hayden v. White Separators.*

VARIETY.	Quantity of Fruit placed in Storage Test (Bushels).	How cleaned.	Date separated.	Date screened.	Date examined to determine Rot Percentage.	Percentage of Rotten and Partly Rotten Berries at End of Storage Test.
Howes,	4	Hand-screened only,	-	Oct. 26	Dec. 21,	12.59
	4	Hayden separator and hand-screened,	Oct. 25	Oct. 26	Dec. 20 and 21,	14.46
	4	White separator and hand-screened,	Oct. 25	Oct. 26	Dec. 20 and 21,	14.19
McFarlin,	4	Hand-screened only,	-	Oct. 26	Dec. 20 and 21,	12.34
	4	Hayden separator and hand-screened,	Oct. 25	Oct. 26	Dec. 20 and 21,	19.20
	4	White separator and hand-screened,	Oct. 25	Oct. 26	Dec. 20 and 21,	19.36

The figures of the table indicate that, in both tests, the White machine apparently affected the keeping qualities of the fruit about the same as did the Hayden. This result is surprising, and must be verified by future experiments. The difference in the tendency to rot between the separated and unseparated berries was not as great as in last year's tests. This may have been partly due to the injury that all the lots of fruit probably received in the carting, this perhaps partly hiding the real difference in the damage done by the various methods of cleaning.

9. *The Injury to the Keeping Quality of Cranberries caused by Separators employing the Bouncing Principle and by the Drop in the Barrel.* — That this varies greatly with different lots of berries was indicated by the results of half a dozen minor experiments conducted by Dr. Stevens. The range in the increase of decay caused by these factors in these tests was from about 14 to about 127 per cent.

A new arrangement devised by the writer for preventing the barrel injury, for use both in screening and in connection with separators, works well mechanically and promises to be generally satisfactory, though no storage tests have been conducted to determine the degree of its effectiveness. This device is on exhibition at the offices of the New England Cranberry Sales Company, Middleborough, Mass., and the J. J. Beaton Growers' Agency, Wareham, Mass., and it also may be seen at the station screenhouse at East Wareham at any time during the cranberry season.

10. *The Effect of Grading on the Keeping of Cranberries.* — The two following series of tests come under this head: —

(*a*) Two lots of Early Black berries picked in the same location on the station bog were treated as shown in Table 14. To make sure of their being well cleaned they were run through a Hayden separator twice immediately before they were stored. Only the berries going into the separator barrels were used in the test. Neither lot was hand-screened. They were stored in bushel picking crates of the same dimensions and construction. The Hayden grader was used. A board was in the grader frame in place of the grader while the second lot was run through. The spacing of the grader, fourteen thirty-seconds of an inch, was wider than that commonly used, and it took out from a fifth to a quarter of the entire quantity of berries put through the separator while it was in use.

TABLE 14. — *Effect of Grading on Keeping of Cranberries, First Test (Early Black Variety).*

Date picked.	Date put through Separator.	Lot Number.	Whether graded or not.	Spacing of Grader used (Inches).	Quantity of Berries placed in Storage Test (Bushels).	Period of Storage Test.	Average Cup-count of Berries at End of Storage Test.	Method of Examination to determine Rot Percentage.	Percentage of Rotten and Partly Rotten Berries found at End of Storage Test.
Oct. 2	Oct. 21	1,	Graded, ...	$\frac{14}{32}$	3	Oct. 21 to Dec. 27	114.3	Nine-sample, . .	28.51
		2,	Not graded, . . .	-	3	Oct. 21 to Dec. 27	122.8	Nine-sample, . .	34.69

The figures of the table show that the closely graded berries kept considerably better than the ungraded ones, there being nearly 22 per cent. more rot among the latter at the close of the test. The cup-counts were taken with the inspectors' cup of the New England Cranberry Sales Company.

(*b*) Two lots of Howes berries were obtained for this series of tests by dividing boxes of fruit, just as they had been stored when they came from the bog on October 7, into equal parts by alternate dippings with a quart measure. They were put through a Hayden separator, with the upper set of bounce-boards set at the middle notch, on December 26. A board five-eighths of an inch thick was kept in the grader frame in place of the grader while the second lot was run through. The grader took out about a quarter of the quantity of berries separated while it was in use. Only the berries that went into the barrels from the separator were used. They were poured from the barrels into boxes and were taken into the warm screening room a box at a time, so that they might undergo a high temperature no longer than necessary during the screening. Both lots were carefully screened at the same time on December 29, the berries being run into picking crates placed close to the mouths of the screens. They were carefully shaken down and stored in these crates at once. The arrangement and results of these tests are shown by Table 15.

It will be seen that after a winter storage of nearly ten weeks almost 32 per cent. more berries showed rot among the ungraded fruit than among that which had been closely graded. At no time during the test did the temperature of the storage room range more than 8° above the freezing point of water, and for considerable periods it ran more or less below it. The cup-counts given in the table were taken, as in the first series of tests, with the Sales Company's cup.

While it cannot safely be said that the results of these tests prove that grading improves the keeping of cranberries, they bring out a point of much importance. Closely graded berries, being larger and more uniform in size, are much more desirable in appearance than ungraded ones. If they also keep better, the advisability of preparing them for market in this way as a means of inducing greater consumption is much confirmed. If close grading were generally practiced it could be made a powerful factor in properly controlling the cranberry market, for, while it tended strongly to increase consumption on one hand, it would in a sense cut down production on the other. In the writer's opinion it would be the best possible means for dealing with overproduction, for if any part of a crop had to be thrown away it would be only the berries of inferior size or quality.

The results of these grading tests are entirely in line with last year's findings of the writer, in the study of ventilation as affecting cranberry keeping, and with those brought out by Dr. Shear and his collaborators in their paper published as a part of this bulletin. The small berries as well as the leaves, conclusive experiments with which are described above (No. 7, page 206), might be expected to check ventilation, not only by

TABLE 15. — *Effect of Grading on Cranberry Keeping, Second Test (Howes Variety).*

Lot No.	WHETHER GRADED OR NOT.	Spacing of Grader used.	Quantity of Berries placed in Storage Test (Bushels).	Period of Storage Test.	Method of Examination to determine Rot Percentage.	Box Number.	Average Cup-count of Berries at End of Storage Test.	Percentage of Rotten and Partly Rotten Berries found at End of Storage Test.
1,	Graded,	Half-inch,	4	Dec. 29 to Mar. 7,	Seven-sample,	1	95.3	22.0
						2	96.7	17.6
						3	95.0	20.2
						4	97.1	21.9
							96.0[1]	20.4[1]
2,	Not graded,		5	Dec. 29 to Mar. 7,	Seven-sample,	1	104.9	27.0
						2	106.6	33.2
						3	103.6	26.5
						4	108.1	24.8
						5	106.3	23.0
							105.9[1]	26.9[1]

[1] Average.

mechanically reducing the spaces for the passage of air and gases among the fruit, but also by themselves using up oxygen and giving off additional carbon dioxide, in this way being especially harmful.

11. *The Relative Effect of Barrel and Crate Containers on Cranberry Keeping in Shipments.* — Three lots of Early Black and two lots of Howes berries, each lot consisting of a barrel and two half-barrel crates, made up an experimental shipment to determine this. All the berries of each lot came from the same place on the station bog, the different lots being picked in various locations, the Early Black on October 2 and the Howes on October 5. All five lots were run through a Hayden separator and screened on November 7. On account of difficulties encountered in arranging for shipping this fruit with other berries in a carload, it was then kept in open barrels, all of which were nearly full, until November 17, when it was packed for shipment. The berries shipped in barrels were packed in the usual way, while the crated fruit was placed in 4-quart baskets like those used as containers for strawberries.[1] All the lots were left in the packed condition in a cold room until November 20, when they were carted in a farm wagon (without springs) from East Wareham to Tremont Station. They were kept in the railroad freight-house over night and placed in different parts of a car on top of a carload of other berries the next morning. The car left Tremont November 21 and arrived in Washington, D. C., on Saturday, November 25. They were there left in the freight-house until the following Monday morning. They were then taken to Arlington Farm and stored at a temperature of about 50° F. until December 9. The barrels and crates were opened and stored in a laboratory, the temperature of which varied from 60° to 85° F., from December 9 until December 14 and 15, when they were sampled and examined, as follows: —

(*a*) The eight following samples were taken from each barrel: —

Nos. 1 and 2, two quarts near the top, just below the layer crushed in heading, — distinguished in Table 16 by the word "top."

No. 3, one quart taken a quarter of the distance down from the top, — indicated by "¼".

Nos. 4 and 5, two quarts taken near the middle, — marked "½".

No. 6, one quart taken from three-quarters of the distance from the top toward the bottom, — designated as "¾".

Nos. 7 and 8, two quarts from near the bottom, — distinguished as "bottom."

The berries were dipped out of the barrels down to the parts sampled, the samples being taken from all parts of the surface of the fruit exposed by the dipping, except within 2 inches of the staves.

(*b*) Four 1-quart samples were taken from each crate of each lot at various places in the crate, so as to make up as fair an average as possible, each sample representing different baskets.

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[1] The crates and baskets were furnished through the courtesy of Mr. J. J. Beaton of Wareham, Mass.

TABLE 16. — *Barrels v. Crates as Containers for Shipping Cranberries. Record of Examination of Experimental Lots shipped to Washington, D. C.*

SAMPLES.	SHIPMENT — LOTS.														
	1. EARLY BLACK.			2. EARLY BLACK.			3. EARLY BLACK.			4. HOWES.			5. HOWES.		
	Number of Sound Berries in the Sample.	Number of Rotten and Partly Rotten Berries in the Sample.	Percentage of Rotten and Partly Rotten Berries.	Number of Sound Berries in the Sample.	Number of Rotten and Partly Rotten Berries in the Sample.	Percentage of Rotten and Partly Rotten Berries.	Number of Sound Berries in the Sample.	Number of Rotten and Partly Rotten Berries in the Sample.	Percentage of Rotten and Partly Rotten Berries.	Number of Sound Berries in the Sample.	Number of Rotten and Partly Rotten Berries in the Sample.	Percentage of Rotten and Partly Rotten Berries.	Number of Sound Berries in the Sample.	Number of Rotten and Partly Rotten Berries in the Sample.	Percentage of Rotten and Partly Rotten Berries.
Barrel samples: —															
1 (top),	379	236	38.4	385	205	34.7	398	131	24.8	321	84	20.7	397	97	19.6
2 (top),	374	234	38.5	398	224	36.0	393	172	30.5	329	83	20.1	373	121	24.5
3 (¼),	308	246	44.4	340	211	38.3	289	212	42.3	387	129	25.0	428	81	15.9
4 (½),	327	210	39.1	397	190	33.4	355	205	36.6	379	107	21.2	421	84	16.6
5 (½),	310	240	43.6	309	235	43.2	373	178	32.3	342	156	31.3	418	96	18.7
6 (¾),	290	224	43.6	323	237	42.3	282	276	49.5	388	125	24.4	410	95	18.8
7 (bottom),	356	196	35.3	347	216	38.4	324	232	41.7	404	110	21.4	420	98	18.9
8 (bottom),	354	159	31.0	368	209	36.2	325	205	38.7	392	113	22.4	399	113	22.1
Totals of barrel samples,	2,698	1,745	39.3	2,849	1,727	37.7	2,739	1,611	37.0	2,960	907	23.5	3,266	785	19.4
Crate samples: —															
1,	404	147	26.7	391	192	32.9	380	134	26.1	468	53	10.2	499	37	6.9
2,	401	167	29.4	404	184	31.3	443	121	21.5	473	84	15.1	495	39	7.3
3,	395	121	23.5	406	210	34.1	405	137	25.3	417	76	15.4	499	62	11.0
4,	402	151	27.3	397	186	31.9	430	191	30.8	471	53	10.1	462	30	6.1
5,	410	172	29.6	433	121	21.8	397	187	32.0	468	68	12.7	478	45	8.6
6,	415	190	31.4	382	191	33.3	441	140	24.1	464	62	11.8	460	34	6.9
7,	403	169	29.6	387	176	31.3	397	155	28.1	454	69	13.2	492	38	7.2
8,	424	144	25.3	403	166	29.2	399	150	27.3	443	77	14.8	442	72	14.0
Totals of crate samples,	3,254	1,261	27.9	3,203	1,426	30.8	3,292	1,215	27.0	3,658	542	12.9	3,827	357	8.5
Percentage of berries showing decay in the barrels as compared with those in the crates,	141			122			137			182			228		

The sampling was done by Dr. Stevens. The results of his examinations are given in Table 16. They show that the crated fruit was in much better condition than that in barrels in all the lots, especially those of the Howes variety.

The results of these tests accord with the conclusions given in last year's report (pages 23 and 24) regarding the use of crates instead of barrels as shipping containers for cranberries. These results were confirmed by those obtained with shipments of berries from another bog to Portland, Me., made by Dr. Stevens, but not described here.

12. *The Relative Development of Decay in Different Periods of the Storage Season.* — The four series of tests to determine this were conducted as follows: —

(*a*) On September 22, 20 quart cans were filled with entirely sound berries from each of 7 half-filled crates of Early Black fruit picked at the same time in the same general location on the station bog three days before. This fruit was stored at once, and the different 20-can lots were examined one after another at intervals of two weeks.

(*b*) On October 4, 10 quart cans were filled with sound berries from each of 12 half-filled crates of Howes fruit picked at the same time and in the same place on the station bog the day before. These cans were stored at once, and the different 10-can lots were examined one after another at weekly intervals.

(*c*) Quart cans were filled with sound Early Black fruit in lots of 10, from each of 13 half-filled crates successively, at weekly intervals from September 20 to December 13, inclusive, the berries all having been picked at the same time and in the same general location on the station bog on September 19. The cans of each lot were stored as soon as filled and were examined at the end of a two-week storage.

(*d*) Quart cans were filled with sound Howes fruit in lots of 10, from each of 11 half-filled crates successively, at weekly intervals from October 4 to December 13, inclusive, the berries all having been picked at the same time and in the same location on the station bog on October 3. The cans of each lot were stored as soon as filled and were examined at the end of a two-week storage.

The arrangement and results of all these series of tests are given in order in Table 17. They failed to show any distinct difference in the rate of rot development in the various periods of the storage season, this general result differing from that of last year's experiment[1] in this connection. The writer now thinks that the handling of the berries in selecting them for these tests, and their lack of ventilation in the tightly covered cans, may have so affected their keeping as to hide different results that perhaps would have been obtained under more normal storage conditions. The description of the tests is included here for its possible value in making future comparisons, and as a record of work done. Further experiments along this line should be tried.

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[1] Bul. No. 168, Mass. Agr. Expt. Sta., 1916, p. 18.

TABLE 17. — *Rot Development among Cranberries stored in Tin Cans in Different Periods of the Storage Season.*

TEST AND VARIETY.	Quantity of Berries used (Quarts).	Date stored.	Date examined to determine Rot Percentage.	Total Number of Berries.	Number of Rotten and Partly Rotten Berries when examined after Storage.	Percentage of Rotten and Partly Rotten Berries found at End of Storage.
(*a*), Early Black, . . .	20	Sept. 22	Oct. 6	11,415	450	3.94
	20	Sept. 22	Oct. 20	11,641	1,516	13.02
	20	Sept. 22	Nov. 3	11,506	3,069	26.67
	20	Sept. 22	Nov. 17	11,630	4,167	35.83
	20	Sept. 22	Dec. 1	11,781	5,118	43.44
	20	Sept. 22	Dec. 15	11,599	6,316	54.45
	20	Sept. 22	Dec. 29	11,412	6,532	57.24
(*b*), Howes, ...	10	Oct. 4	Oct. 11	4,903	71	1.45
	10	Oct. 4	Oct. 18	4,905	100	2.04
	10	Oct. 4	Oct. 25	4,960	228	4.60
	10	Oct. 4	Nov. 1	4,961	418	8.43
	10	Oct. 4	Nov. 8	4,888	503	10.29
	10	Oct. 4	Nov. 15	4,981	776	15.58
	10	Oct. 4	Nov. 22	4,948	860	17.38
	10	Oct. 4	Nov. 29	4,877	939	19.25
	10	Oct. 4	Dec. 6	4,894	1,147	23.44
	10	Oct. 4	Dec. 13	5,029	1,494	29.71
	10	Oct. 4	Dec. 20	4,821	1,353	28.06
	10	Oct. 4	Dec. 27	4,845	1,553	32.05
(*c*), Early Black, . . .	10	Sept. 20	Oct. 4	5,779	301	5.21
	10	Sept. 27	Oct. 11	5,530	308	5.57
	10	Oct. 4	Oct. 18	5,602	137	2.45
	10	Oct. 11	Oct. 25	5,782	222	3.24
	10	Oct. 18	Nov. 1	5,441	240	4.41
	10	Oct. 25	Nov. 8	5,363	140	2.61
	10	Nov. 1	Nov. 15	5,379	201	3.74
	10	Nov. 8	Nov. 22	5,487	220	4.01
	10	Nov. 16	Nov. 30	5,693	295	5.18
	10	Nov. 22	Dec. 6	5,684	315	5.54
	10	Nov. 29	Dec. 13	5,510	307	5.57
	10	Dec. 6	Dec. 20	5,763	304	5.28
	10	Dec. 13	Dec. 27	5,513	476	8.63

TABLE 17. — *Rot Development among Cranberries stored in Tin Cans in Different Periods of the Storage Season* — Concluded.

TEST AND VARIETY.	Quantity of Berries used (Quarts).	Date stored.	Date examined to determine Rot Percentage.	Total Number of Berries.	Number of Rotten and Partly Rotten Berries when examined after Storage.	Percentage of Rotten and Partly Rotten Berries found at End of Storage.
(*d*), Howes,	10	Oct. 4	Oct. 18	4,643	118	2.54
	10	Oct. 11	Oct. 25	4,730	104	2.20
	10	Oct. 18	Nov. 1	4,908	191	3.89
	10	Oct. 25	Nov. 8	4,570	117	2.56
	10	Nov. 1	Nov. 15	4,546	103	2.27
	10	Nov. 8	Nov. 22	4,633	129	2.78
	10	Nov. 15	Nov. 29	4,808	116	2.41
	10	Nov. 23	Dec. 7	4,747	112	2.36
	10	Nov. 29	Dec. 13	4,915	145	2.95
	10	Dec. 6	Dec. 20	4,943	155	3.14
	10	Dec. 13	Dec. 27	4,849	142	2.93

13. *Incubator Test of Keeping Quality of Cranberries.* — A few lots of Early Black berries were moistened and tested as to their keeping quality in quart cans, with the covers on tight but not sealed, in a chicken incubator run at a temperature of 80° F. The results seemed to show that the relative keeping quality of cranberries can be determined in this way in a period of about forty-eight hours.

Tentative Practical Conclusions based on the Results of the Storage Tests.

1. Cranberries should not be picked wet.

2. Scoop-picking is not particularly harmful to keeping quality.

3. Deep scooping is likely to affect cranberrry keeping adversely because it gathers maximum amounts of under berries, loose leaves and sand, these materials being harmful in storage.

4. Cranberries left in the sun on the bog for a good part of the day during picking seem to keep about as well as those housed at once, under average storage-house conditions. There might be a great difference in this regard, however, if cooler storage were practiced, for the relatively high temperature usually had by the berries when they are picked probably has a hurtful effect, hence the sooner they are cooled the better.

5. Lack of sufficient ventilation affects cranberry keeping adversely, apparently by interfering with the process of respiration, not by prevent-

ing the evaporation of moisture, as suggested in last year's report (pages 6 to 17). Cranberries, like other fruits, are living, breathing organisms when picked, and must take in oxygen and give off carbon dioxide freely to continue their life processes. They may do this for several months after they are taken from the vines. Lack of ventilation probably affects them in much the same way that smothering does an animal, — by permitting the accumulation of the carbon dioxide gas given off by their tissues and thus reducing their supply of oxygen. The harmful effect of the carbon dioxide appears to be pretty well demonstrated by the experiments described by Dr. Shear and his associates in another part of this bulletin (page 237). This gas appears to collect in injurious quantities among cranberries, both in storage and shipment, because of the closeness with which the fruit packs together and of the size of the containers used.

As has been so splendidly demonstrated with apples,[1] the rapidity of the life processes in fruits varies directly with temperature, much more carbon dioxide being given off at high than at low temperatures. While cranberries may not behave exactly as apples do, it seems to follow that low temperatures are important to cranberry keeping both in storage and shipment, for with such temperatures the need of ventilation is probably less.

The general problem divides itself naturally into two parts, as follows: —

(*a*) *Storage previous to Shipment* — Low temperatures, because of their retarding effect on the process of respiration and on the growth of rot-producing fungi, seem most important. The storage house, therefore, probably should be constructed and managed to maintain such temperatures, without resorting to artificial cold storage, at as little expense as possible. This in turn, however, is likely in practice to depend largely on arrangements for free but controllable ventilation. If, as the results of the experiments described by Dr. Shear and his collaborators on page 238 seem to tend to show, a damp atmosphere does not injure the keeping of this fruit, the thorough ventilating of the storage room during the night and on cold days would be the cheapest means of obtaining low temperatures, and they probably should be maintained as far as possible by the use of dead-air spaces in the walls. To combine satisfactory arrangements for free but controllable ventilation and for effective heat insulation at a reasonable expense is probably, therefore, the main problem to be solved by future builders of cranberry storage houses. Artificial cold storage for cranberries has not been investigated much yet, and therefore is not considered here.

(*b*) *Preparation for Shipment.* — While a low temperature is still probably desirable for cranberries after they leave the producer, this factor, except as it may be utilized by cooling previous to shipment or by shipping in refrigerator cars, is largely out of his control. He should, therefore, make the most of careful handling of the fruit in packing and of proper ventilation for it while in transit and in the market. The latter seems to call especially for close grading and for the use of as small and open containers as practicable.

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[1] F. W. Morse, Bul. No. 135, New Hampshire Agr. Expt. Sta., 1908, and Journal of the American Chemical Society, Vol. 30, No. 5, 1908.

6. The separator problem is still unsolved.

Resanding.

The year's experience with the plots, results with which have been discussed in previous reports, is shown in Table 18. The check areas were in each case laid out adjacent to and on opposite sides of the plot. All the plots and checks were picked with scoops. The storage-test berries were selected by handfuls from different parts of the crates as they came from the bog and put in quart cans, each can representing one crate. The cans were stored with covers on tight but not sealed.

This, the seventh year since resanding was discontinued on plots O and V, is the first one except 1913 in which their yield has been noticeably reduced as compared with that of the checks. Throughout the season these unsanded plots presented a marked contrast to the surrounding bog which was resanded in 1912 and 1914, their vines being comparatively very thin and sickly in appearance.

TABLE 18. — *Sanding Plots in 1916. Effect of Resanding on Quantity and Keeping Quality of Cranberries.*

PLOTS AND CHECKS.	Area (Square Rods).	Variety.	When resanded.	Date picked.	Quantity of Fruit obtained (Bushels).	Quantity of Fruit per Square Rod (Bushels).	Quantity placed in Storage Test (Quarts).	Period of Storage Test.	Percentage of Rotten and Partly Rotten Berries found at End of Storage Test.
V,	9	Early Black,	Not since November, 1909,	Sept. 27	8.33	.93	8	Sept. 27 to Nov. 27	62.76
V (check 1),	9	Early Black,	Spring of 1912 and fall of 1914,	Sept. 27	13.33	1.48	8	Sept. 27 to Nov. 27	54.01
V (check 2),	6	Early Black,	Spring of 1912 and fall of 1914,	Sept. 27	9.00	1.50	8	Sept. 27 to Nov. 27	55.26
V (check 3),	9	Early Black,	Spring of 1912 and fall of 1914,	Sept. 27	10.60	1.18	8	Sept. 27 to Nov. 28	58.88
O,	9	Early Black,	Not since November, 1909,	Sept. 26	8.33	.93	8	Sept. 26 to Nov. 28	54.46
O (check 1),	9	Early Black,	Fall of 1911 and fall of 1914,	Sept. 26	13.00	1.44	8	Sept. 26 to Nov. 28	31.74
O (check 2),	7½	Early Black,	Fall of 1911 and fall of 1914,	Sept. 26	8.13	1.08	8	Sept. 26 to Nov. 28	50.89
O (check 3),	9	Early Black,	Fall of 1911 and fall of 1914,	Sept. 26	10.67	1.19	8	Sept. 26 to Nov. 29	45.48
N,	9	Early Black,	Yearly in the fall, 1911 to 1915, inclusive,	Sept. 28	12.25	1.36	8	Sept. 28 to Nov. 23	37.63
N (check 1),	9	Early Black,	Fall of 1911 and fall of 1914,	Sept. 28	12.50	1.39	8	Sept. 28 to Nov. 23	33.38
N (check 2),	9	Early Black,	Fall of 1911 and fall of 1914,	Sept. 28	14.25	1.58	8	Sept. 28 to Nov. 23	37.35
N (check 3),	9	Early Black,	Fall of 1911 and fall of 1914,	Sept. 28	13.50	1.50	8	Sept. 28 to Nov. 23	38.92
R,	9	Early Black,	Yearly in the fall, 1911 to 1915, inclusive,	Sept. 25	9.13	1.01	8	Sept. 25 to Nov. 25	37.12
R (check 1),	5	Early Black,	Fall of 1911 and fall of 1914,	Sept. 25	6.50	1.30	8	Sept. 25 to Nov. 25	27.75
R (check 2),	6	Early Black,	Fall of 1911 and fall of 1914,	Sept. 25	6.83	1.14	8	Sept. 25 to Nov. 25	31.67
T,	9	Howes,	Yearly in the fall, 1911 to 1915, inclusive,	Oct. 4	11.17	1.24	8	Oct. 4 to Nov. 21	21.55
T (check 1),	9	Howes,	Fall of 1911 and fall of 1914,	Oct. 4	10.67	1.19	8	Oct. 4 to Nov. 21	19.98
T (check 2),	9	Howes,	Fall of 1911 and fall of 1914,	Oct. 4	13.60	1.51	8	Oct. 4 to Nov. 21	18.87

Summary of Table 18.

PLOTS AND CHECKS.	Total Area (Square Rods).	When resanded.	Total Quantity of Fruit picked (Bushels).	Average Quantity of Fruit per Square Rod (Bushels).	Average Percentage of Rotten and Partly Rotten Berries at End of Storage Test.
Plots O and V,	18	Not since November, 1909,	16.66	.93	58.61
Checks O and V,	49½	Twice since 1909,	64.73	1.31	49.38
Plots N, R and T,	27	Yearly in the fall, 1911 to 1915, inclusive.	32.55	1.21	32.10
Checks N, R and T,	56	Twice since 1909,	77.87	1.39	29.70

The keeping qualities of the fruit of the sanding plots and their checks were determined by storage tests each year from 1912 to 1916, inclusive. The results of these tests and their averages are given in the following table: —

TABLE 19. — *Effect of Resanding on Keeping Quality.*

PLOTS AND CHECKS.	Variety.	Area (Square Rods).	When resanded.	PERCENTAGES OF ROTTEN AND PARTLY ROTTEN BERRIES AT END OF STORAGE TESTS.					
				1912.	**1913.**	**1914.**	**1915.**	**1916.**	Average for the Five Years.
V,	Early Black,	9	Not since 1909,	15.60	36.75	30.39	29.32	62.76	34.96
V (checks),	Early Black,	13½ to 24	Spring of 1912 and fall of 1914,	18.75	41.20	23.53	29.62	56.05	33.83
O,	Early Black,	9	Not since 1909,	15.30	29.40	27.94	19.95	54.46	29.41
O (checks),	Early Black,	18 to 25½	Fall of 1911 and fall of 1914,	21.90	28.90	31.37	23.79	42.70	29.73
N,	Early Black,	9	Yearly in the fall, 1911 to 1915, inclusive,	Not started	38.25	24.51	19.21	37.63	29.90
N (checks),	Early Black,	12 to 27	Fall of 1911 and fall of 1914,	-	30.14	19.61	17.70	36.55	26.00
R,	Early Black,	9	Yearly in the fall, 1911 to 1915, inclusive,	Not started	36.00	24.51	20.86	37.12	29.62
R (checks),	Early Black,	6 to 12	Fall of 1911 and fall of 1914,	-	34.20	24.51	17.25	29.71	26.42
T,	Howes,	9	Yearly in the fall, 1911 to 1915, inclusive,	Not started	38.75	18.14	13.53	21.55	22.99
T (checks),	Howes,	15 to 24	Fall of 1911 and fall of 1914,	-	29.40	13.73	13.65	19.43	19.05

FERTILIZERS.

The season's results with the station bog fertilizer plots are given in Table 20. The area of each plot, as stated in the report for 1912, is 8 square rods, and the variety of berries tested is the Early Black. The plots are on a peat bog with a covering of sand ranging from 6 to 8 inches in thickness.

TABLE 20. — *Fertilizer Plots in 1916. Yield and Relative Keeping Quality of Berries.*

Plot.	FERTILIZER USED.	Date treated in 1916.	Date picked.	Quantity of Berries produced (Bushels).	Quantity of Berries in Storage Test (Quarts).	Date Stored Berries were examined to determine Rot Percentage.	Percentage of Rotten and Partly Rotten Berries found at End of Storage Test.
1	0,	– –	Sept. 22	10.67	8[1]	Dec. 4	46.86
2	N,	June 24	Sept. 22	9.33	8	Dec. 4	50.21
3	P,	June 24	Sept. 22	9.00	8	Dec. 4	45.90
4	K,	June 24	Sept. 22	9.60	8	Dec. 4	53.78
5	0,	– –	Sept. 22	9.20	8	Dec. 4	49.61
6	NP,	June 24	Sept. 22	6.33	8	Dec. 5	57.64
7	NK,	June 24	Sept. 22	6.60	8	Dec. 5	56.33
8	PK,	June 26	Sept. 22	8.00	8	Dec. 7	49.00
9	0,	– –	Sept. 22	9.00	8	Dec. 7	45.14
10	NPK,	June 27	Sept. 22	6.88	8	Dec. 7	43.80
23	Peat[2],	– –	Sept. 22	8.00	8	Dec. 9	39.39
11	NPKL,	June 27	Sept. 23	2.86	8	Dec. 7	59.07
12	NPKcl,	June 27	Sept. 23	6.00	8	Dec. 7	50.98
13	0,	– –	Sept. 23	7.67	8	Dec. 8	41.12
14	$N_{1\frac{1}{2}}PK$,	June 26	Sept. 23	5.50	8	Dec. 8	55.84
15[3]	N_2PK,	June 26	Sept. 23	4.52	12	Dec. 8	63.10
16	$NKP_{1\frac{1}{2}}$,	June 26	Sept. 23	7.20	8	Dec. 8	55.81
17	0,	– –	Sept. 23	9.33	8	Dec. 8	39.87
18	NKP_2,	June 26	Sept. 23	8.33	8	Dec. 8	47.36
19	$NPK_{1\frac{1}{2}}$,	June 26	Sept. 23	7.75	8	Dec. 8	53.08
20	NPK_2,	June 26	Sept. 23	9.00	8	Dec. 8	59.94
21	0,	– –	Sept. 23	10.33	8	Dec. 8	49.63

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[1] The storage-test berries from each plot were stored, without being run through a separator or otherwise cleaned, in quart cans on the day they were picked, each can being filled with handfuls of fruit taken from different parts of a separate picking crate, its contents thus representing as fairly as possible the contents of the crate as it came from the bog. The covers of the cans fitted tightly during the storage, but were not sealed.

[2] Leaf mold worked into a condition in which it could be spread easily with a shovel.

[3] The figures for plot 15 are probably misleading, as half of that plot was used in spraying tests with Bordeaux mixture in 1913, 1914 and 1915, and certain effects of that treatment may have remained in 1916; though, if the whole plot had yielded at the same rate as did the portion that never had been sprayed, it would have produced only 5.33 bushels. The rot percentage given for this plot is an average of the percentages obtained in the tests of the fruit of the sprayed and the unsprayed parts.

Plots 1, 5, 9, 13, 17 and 21 are all untreated checks. The meanings of the symbols used in the table are as follows: —

0 = Nothing.
N = 100 pounds nitrate of soda per acre.
P = 400 pounds acid phosphate per acre.
K = 200 pounds high-grade sulfate of potash per acre.
L = 1 ton of (slaked) lime per acre.
Kcl = 200 pounds muriate of potash per acre.
$N_{1\frac{1}{2}}$ = 150 pounds nitrate of soda per acre.
N_2 = 200 pounds nitrate of soda per acre.
$P_{1\frac{1}{2}}$ = 600 pounds acid phosphate per acre.
P_2 = 800 pounds acid phosphate per acre.

In combination they mean, for example, as follows: N_2PK = 200 pounds of nitrate of soda + 400 pounds of acid phosphate + 200 pounds of high-grade sulfate of potash per acre.

As the table shows, the fruit of the fertilized areas this season was, as a rule, much inferior in both quantity and keeping quality to that of the checks, this being especially marked with the plots treated with lime and with the maximum amount of nitrate of soda. Considering all the experience with these plots since they were started in 1911, it is the writer's judgment that, in general, whatever slight advantage in yield has been gained by the use of the fertilizers has been balanced by the cost of the treatment, the deterioration in the quality of the fruit and the greater cost of picking due to the increased vine growth.

Insects.

The Cranberry Rootworm (*Rhabdopterus picipes* (Oliv.)).

The rearing of the beetles definitely identified the infestation by the cranberry rootworm (*Rhabdopterus picipes* (Oliv.)) tentatively recorded in last year's report (pages 32 and 33). By the beginning of winter the grubs of this insect nearly complete their growth. They are then, except the head, for the most part nearly white in color and somewhat over a quarter of an inch long. They hibernate without growing larger. They do some feeding in the spring and change into pupæ in June. No beetles of the infestation under observation had yet emerged on June 30, this season, a collection of the insects taken that day consisting of 4 grubs and 32 pupæ. One beetle was found on July 1, and during the following two weeks they practically all came out, the period of most rapid emergence extending from the 3d to the 11th of the month.

It was anticipated that the adults might feed freely on the cranberry foliage, and at the writer's suggestion an arsenical spray was applied to the infested area on July 3 and repeated on the 11th and 18th. In the first two applications, 2¼ pounds of "Corona" arsenate of lead and 1 heaping teaspoonful of white arsenic to 40 gallons of water were used. For the last treatment the mixture was the same, except that the arsenic was increased to 1½ teaspoonfuls to 40 gallons. The writer suggested only the arsenate of lead, fearing arsenic would do harm. The latter was added by the foreman of the bog to do a thorough job, and fortunately no injury resulted.

The writer visited the bog on July 20 and found dead rootworm beetles in large numbers under the vines, most of them being in a dry and brittle condition. Only a very few were crawling about. The cranberry foliage on the infested area showed that the beetles had fed freely upon it. As 6 of 15 beetles, collected July 11 and kept at the station screenhouse, were still active on the 26th, the condition of those found on the bog on the 20th seemed to indicate that the spraying had been effective. This bog was kept under observation until the end of the season, and no evidence of the continued presence of the pest was discovered, it having been practically exterminated by the treatment.

Prof. H. B. Scammell has published a valuable bulletin on this insect.[1]

The Gypsy Moth (*Porthetria dispar* L.).

Several quarts of egg masses were collected from trees late in December, 1915, and early in January, 1916, and divided into lots of about a half quart each, two of these being put in cans with moist sand in the bottom and placed in the basement of the station screenhouse for checks, the others being enclosed in cloth netting sacks and submerged for the winter in 3 feet of water in a pond.

The eggs of the check lots hatched almost perfectly. The dates on which the various submerged lots were taken from the water, and the writer's estimates of the percentages of eggs that hatched, were as follows: lot 1, April 2, 25 per cent.; lot 2, April 18, 20 per cent.; lot 3, April 23, 18 per cent.; lot 4, May 1, 25 per cent.; lot 5, May 5, 20 per cent.; lot 6, May 13, 20 per cent.; lot 7, May 24, 5 per cent. The submergence did not seem to kill the eggs as readily in these tests as in those reported last year. This may have been due to the unseasonable coldness of the spring this season, which probably caused the water in the pond to warm up more slowly than usual.

On May 29, 59 gypsy-moth caterpillars from one-eighth to five-sixteenths of an inch long were submerged on the leaves of an oak branch just as they were taken from the woods, in 8 inches of water in a washtub. All but 3 of the worms clung to the branch and went down into the water with it. At the end of a forty-three-hour submergence, 8 floated on the surface, 4 had sunk to the bottom of the tub, and 47 still clung to the leaves. These worms were watched for two days after the close of the test, but only 1 of the 59 showed any sign of life.

On May 31, 50 caterpillars from one-quarter to five-sixteenths of an inch long were submerged, as before, on the leaves of an oak branch in 9 inches of water. All these worms clung to the leaves tenaciously when submerged. After twenty-two hours in the water, 2 floated on the surface,

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[1] **The Cranberry Rootworm, Bul. No. 263, U. S. Dept. Agr., 1915.**

3 had sunk to the bottom, and 45 still clung to the leaves. They were then taken from the water, and within seven hours 26 had nearly or entirely recovered.

On June 1, 152 worms from one-quarter to three-eighths of an inch long were submerged on the leaves of an oak branch, as before, in 9 inches of water. After thirty-eight and one-half hours of submergence, 46 floated on the water, most of them being alive and active, 40 had sunk to the bottom, and 66 still clung to the leaves. Those clinging to the branch were then taken from the water and watched, and only a few ever showed any sign of recovery. As a rule, the worms that came to the surface of the water were among the largest of those submerged, as was also the case in later tests, descriptions of which are not included here.

The results of these experiments and of observations of bog flooding operations, in which the small gypsy caterpillars behaved similarly, have led the writer to the following conclusions: —

1. That reflowing for this insect will be most satisfactory if done while the worms are small and probably before the largest are more than five-sixteenths of an inch long. The sooner it is done after the eggs are all hatched the less will be the damage from the feeding of the worms and the less the trouble from their floating ashore alive, as it is evidently the habit of the very young caterpillars to cling to their support when submerged.

2. To be entirely effective, even when the worms are small, a flowage must probably be held nearly forty hours.

Mr. C. W. Minott of the Bureau of Entomology of the United States Department of Agriculture conducted some interesting investigations during May and June, 1916, concerning the wind-spread of gypsy-moth caterpillars on cranberry bogs. With his permission the following condensed account of these studies is given here: —

> Two bogs in Carver, Mass., were selected for experiments on wind dispersion, namely, Muddy Pond bog, containing about 100 acres, and John's Pond bog, containing about 44 acres (including pond). Six screens made of cotton cloth tacked to a frame in two sections, each being 3 by 10 feet, were set up horizontally just above the tops of the vines at various distances from the neighboring woodlands. Each screen contained 60 square feet of cloth upon which "tanglefoot" was applied. Daily examinations of each screen were made and data were taken concerning the temperature and the direction and velocity of the wind during the dispersion period.
>
> The screens were located on the bogs at various distances, ranging from 400 to 1,200 feet, from woodland infestations. From one screen, located 600 feet from infested woodland on the northwest and 900 feet on the west, 62 small caterpillars were removed during the season, or slightly more than 1 to the square foot. A total of 143 small worms was wind-borne on to the six screens, which indicated that an average of about 17,000 per acre blew on to the bogs. The infestations around these bogs are as yet only medium in extent, this showing what may be expected when the surroundings of bogs become thickly infested.[1]

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[1] Collins, C. W.: Methods used in determining Wind Dispersion of the Gipsy Moth and Some Other Insects, Journal of Economic Entomology, Vol. 10, p. 174, 1917.

The Cranberry Tip Worm (*Dasyneura vaccinii* Smith [1]).

The season's observations of the effect of resanding on the abundance of this pest sustained the conclusions heretofore reported.

One species of Chalcidid (*Tetrastichus* sp. [2]) and two of Proctotrypid (*Aphanogmus* sp. [3] and *Ceraphron* sp. [3]) parasites were reared from the larvæ of the last brood after they had encased themselves in their cocoons this season. Two of these (*Tetrastichus* sp. and *Aphanogmus* sp.) emerged in only small numbers, but the *Ceraphron* species had infested a large, though undetermined, majority of the maggots collected by the writer, and its adults kept coming out from August 9 to September 14, inclusive, their period of most rapid emergence being from August 12 to August 22.

The eggs of the tip worm are not "white" as they have been described.[4] They are watery translucent in appearance, with scattered pinkish pigment, and are about one-third of a millimeter long. They are elongate, usually slightly curved from end to end, with rounded and slightly narrowed ends and without noticeable surface markings.

The Black-Head Fireworm (*Rhopobota vacciniana* (Pack.)).

Prof. H. B. Scammell, in cranberry insect investigations in New Jersey for the Bureau of Entomology, had much success last year in treating both broods of this insect in the worm stage with a form of nicotine sulfate known as "Black-Leaf 40." He used 1 part of this insecticide to 400 parts water, and added resin fish-oil soap at the rate of 2 pounds to 50 gallons to make the spray spread and stick. When the writer saw the plots Professor Scammell had treated in this way, they were green and had a fair amount of fruit, whereas the surrounding bog, and even plots sprayed with arsenate of lead, had been turned brown by the insect and bore practically no crop.

The writer tried this treatment against the first brood on two large plots this season, and while it failed to control the insect entirely, it checked it so much that the plots remained green while the surrounding bog was turned rather brown, the contrast being striking.

This insecticide must be tested further before it can be said at what strength it should be used or how many times it should be applied to either brood. At the strength in which it has so far been tested it is a rather expensive treatment, costing about $7 per acre per application. It may be found, however, that weaker mixtures suffice. At any rate, this treatment stands at present as the only really effective method of controlling the first brood of this insect, burning and flooding excepted, and in spite of its expense it will, therefore, find favor in the management of many bogs. Two, and perhaps three, applications for the first brood are advisable.

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[1] Bul. No. 175 of the New York State Museum, p. 151.

[2] Determined by Mr. A. A. Girault of the Bureau of Entomology.

[3] Determined by Mr. J. C. Crawford of the Bureau of Entomology.

[4] Smith, J. B.: Insects Injurious in Cranberry Culture, Farmers' Bulletin No. 178, U. S. Dept. Agr., 1903, p. 19.

As a treatment for the second brood, it may have to compete with arsenate of lead, for there is danger of injuring tender foliage, and especially blossoms, in spraying with any contact insecticide, and arsenate of lead is far more effective with the second brood than with the first. Proper treatment of the first brood with "Black-Leaf 40" may check the pest so well that a thorough treatment of the second brood will not be so necessary as it is at present. In any case, not more than one application of "Black-Leaf 40" for the second brood is likely to be desirable.

The writer gave some cranberry uprights sprayed with "Black-Leaf 40" to some gypsy-moth caterpillars, providing another lot with unsprayed vines as a check. The latter were eaten much more freely than the former. This suggests that the effectiveness of this insecticide may be partly due to a deterrent property.

The second brood of the fireworm did less damage than usual this season, and less than might have been expected from the abundance of the first brood. The wet season seemed to check it strongly somehow.

The Cranberry Fruit Worm (*Mineola vaccinii* (Riley)).

This insect did the least injury this season of any year in the writer's experience. It has not been less prevalent since 1903. We have no reliable information concerning its abundance in years previous to 1904.

The writer has tried to determine, as far as possible, the relative abundance of this pest in the various cranberry-growing regions. It is most harmful on Cape Cod and in Wisconsin, being far less troublesome in New Jersey, the amount of injury on dry bogs (without winter-flowage) in the latter section, when the writer was there in 1915, being about the same as that on the flowed bogs of the Cape in the same season. It does about the same damage on Long Island and Nantucket as in New Jersey, being far less prevalent there than on Cape Cod. It appears to be almost if not entirely, unknown on the Pacific coast of Oregon and Washington.

It will be seen that *this insect is not usually very troublesome except in the regions with comparatively cold and dry climates, a heavier total precipitation as well as a higher average temperature being characteristic of the warmer sections. One might expect from this that any variation in the Cape Cod climate toward that of the warmer regions would be likely to tend to reduce the pest, whereas any variation in the opposite direction would be likely to tend to make it more abundant.*

Cape Cod Data appear to strongly substantiate this Conclusion. — The season of 1905 was the worst on record for fruit-worm injury. The Cape had a lower mean temperature in 1904 than in any subsequent year up to the present time, and in 1905 had a smaller total precipitation than in any year since, in spite of the fact that the rainfall in all the last five months of the year except October was heavy. Of the severity of the winters 1903–04 and 1904–05, the Annual Summary of the New England Section of the Climate and Crop Service of the Weather Bureau for 1905 (page 3) remarks as follows: —

February — the last of the winter months, with its remarkably low temperature record — completes one of the coldest winters of official record. At Boston the mean temperature for the three months, December, January and February, 1904–05, 24.8 degrees, is the lowest for the winter months since 1871, excepting 24.4 degrees in 1903–04, and 24.5 degrees in 1873–74. The winter for New England, as a whole, was the coldest since the establishment of the weather service of this section in 1884. The mean temperature was 17.9 degrees, and the next lowest is 18 degrees for the winter, 1903–04.

As far as the writer can determine, the greatest reductions in fruit-worm activity in recent years, aside from that of this season, occurred in 1906 and 1913. The records of the Weather Bureau show that the total precipitation of 1906 on the Cape was the greatest of any year since 1904, May, June and July being especially wet months. The winter of 1905–06 was mostly an open one. Both temperature and precipitation ran abnormally high throughout the greater part of the period beginning with October, 1912, and ending May 1, 1913, the winter being very open. As affecting the abundance of the pest in 1916, it should be noted that September, 1915, was a month of record high temperatures for its season, that the winter 1915–16 was mostly very open, and that the first half of this growing season was very wet throughout.

In the latter part of May the writer covered large numbers of fruit worms in their cocoons, in quart cans partly filled with moist sand, with different measured and uniform depths of sand ranging from three-sixteenths of an inch to a full inch, and made records of the subsequent emergence of the adult insects. Unfortunately, no check of worms not covered with any sand was kept for comparison, but, judging from the freedom with which the parasites and moths emerged through three-sixteenths, one-fourth, three-eighths, one-half, five-eighths, two-thirds and even three-fourths inch depths, it appears that resanding as commonly done does not much affect the abundance of either the fruit worm or its worm parasites. The full inch covering of sand seemed to smother most of the moths and parasites, though a few of both came out even from that depth.

The writer liberated a number of apparently female moths from a boat on a pond on July 25, and three of them were seen to fly to the shore, a measured distance of about 272 feet, in a single flight, a toy balloon being anchored in the pond at their point of departure to measure from, and the measuring being done with twine. This demonstration of this insect's powers of flight is of interest in connection with the speculation concerning the annual infestation of bogs from surrounding uplands and from neighboring bogs.

Fruit-worm eggs showed a range in Chalcidid (*Trichogramma minuta*) parasitism of from about 25 to 75 per cent. on dry bogs and from none to about 75 per cent. on those with winter-flowage this year. This parasite was not found at all on half the flowed bogs examined, more than a quarter of the eggs showing its presence on only 3 out of 30 such bogs. It appeared to be entirely absent on some flowed bogs on which it infested from 76 to 89 per cent. of the eggs in 1915. Its great reduction on the flowed bogs may have been due to the long period of wet weather in the first half of the growing season.

The Braconid (*Phanerotoma franklini*[1] Gahan) parasitism was found to range from 24 to about 55 per cent. on dry bogs (without winter-flowage) and from none to about 33 per cent. on flowed ones. On one bog which had the winter-flowage held until May 25, 24 per cent. of the fruit worms were infested with this parasite, and on another, bared of the winter water on May 14, 21 per cent. were infested, these figures indicating that moderately late holding of the flowage perhaps does not reduce this parasite in proportion to its host as seriously as was suggested by the writer in last year's report (page 40.) It should be stated in this connection that the percentages of *Phanerotoma* and *Pristomeridia* parasitism given in this and previous reports only show the amounts of these parasitisms among the worms at work in the berries when the examinations were made, and indicate the parasitism of the entire season only in a very rough way. It was discovered this year that the parasitized worms leave the berries somewhat sooner than the unparasitized ones, examinations made toward the end of the pest's period of activity showing greatly reduced percentages for the worm parasitism as compared with those made earlier. Worms from the same location on one bog showed percentages of *Phanerotoma* parasitism on different dates, as follows: September 3, 33.3 per cent.; September 6, 40 per cent.; September 13, 2.3 per cent. The percentages of *Pristomeridia* parasitism found in this same location were as follows: September 3, 5.5 per cent.; September 6, 6.6 per cent.; September 13, 0.

Pristomeridia agilis[2] was very scarce this year, the percentage of its parasitism being found to range from none to 5½ on flowed bogs and from 4½ to about 10 on strictly dry ones.

The examinations by which the percentages of *Phanerotoma* and *Pristomeridia* parasitism given in this and previous reports were determined were made by crushing fruit worms between glass slides in such a way as to expel their viscera through the anal opening, the parasite larva, when present, apparently always being ejected with them and being found easily with a good hand lens.

A number of eggs deposited at the same time by *Phanerotoma* females under observation in eggs laid by fruit-worm moths in confinement where they were secluded from parasites, and subsequently kept in closed bottles, were examined with a microscope successively at various times after deposition. None of these parasite eggs examined after either thirty-six or forty-two hours showed any sign of hatching. Two of three examined at the end of forty-six hours had hatched, but the larvæ showed no sign of life. After forty-nine hours all the eggs had hatched, and some of the larvæ moved their mouth parts considerably. The weather was cool during the entire period (July 29 and 30) in which this investigation was in progress, the maximum temperature in the sun at the station bog being 80° F. and the minimum bog temperature being 40°.

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[1] This parasite, called *Phanerotoma tibialis* in the writer's previous reports, has recently been described as new to science, and given the name here used, by Mr. A. B. Gahan of the Bureau of Entomology. *Cf.* Proc. U. S. Nat. Mus., Vol. 53, 1917, p. 200.

[2] The exact identity of the species is still in doubt.

Cocoons of parasitized fruit worms are usually much smaller and more delicate than those of unparasitized ones.

Submergence tests were conducted with fruit worms in their cocoons, as follows: —

1. Six small cheesecloth sacks, each containing 20 cocoons, were submerged to a depth of 2 feet in a pond at 10.30 A.M., September 14. They were all taken from the water and examined in the afternoon of September 26, and all the worms were found dead, a majority of them being partly decomposed. Most of them had left their cocoons and were on the inside of the sacks.

2. Three lots of cocoons of 20 each were submerged in cheesecloth sacks to a depth of 2 feet in a pond at 9 A.M., September 30. These were all taken from the water and examined between 11 A.M. and 1 P.M., October 12. All the worms were found dead, most of them being more or less decomposed. About half had left their cocoons and were clinging to the inside of the sacks.

3. Two cheesecloth sacks, each containing 20 cocoons, were submerged in 2 feet of water in a pond at 3 P.M., October 12. These sacks were taken out and examined at 5 P.M., October 24. Most of the worms were found dead and more or less decomposed, as in the previous tests, but 7 were alive in one sack and 2 in the other.

4. Two cheesecloth sacks, each containing 20 cocoons, were submerged to a depth of 2 feet in a pond at 8 A.M., October 25. They were taken out and examined on November 6, 17 being found alive in one sack and 8 in the other.

In all these tests the sacks were of the same material, were tied up and submerged in the same way, to the same depth in the same place and for practically the same length of time. It will be seen that as the season advanced the submergence had much less effect on the worms. As the pond grew colder fast while these tests were in progress their results suggested that the temperature of the water largely determined its effect.

At 1 P.M., Jan. 3, 1917, a weighted cheesecloth sack, containing 15 fruit worms in their cocoons, was placed in the bottom of each of two 1-quart cans full of water, the water being at a temperature of 59½° F., and the cans, with their covers on tight, were placed in a chicken incubator together with Green maximum and minimum registering thermometers, the incubator being set to run at a temperature of 60° F. As a check on these cans, two similar cans containing similar lots of fruit worms were placed in a pail of water at the same time, the temperature of the water in the cans and in the pail around them being about 35° F. The pail, together with maximum and minimum registering thermometers, was placed in a barrel the temperature of the air in which was about 37° F. The barrel was headed up and buried in hay to keep its contents at an even temperature. The cocoons in both the incubator and the barrel were taken from the water at 9 P.M., January 15, and were examined the next day in a warm room. All but 9 of the 30 worms that had been in the incubator were dead, whereas all but 3 of the 30 from the pail were alive. Those taken from the pail were as a rule very lively after they got warmed up, most of them crawling actively. On the other hand, none of those from the incubator became active, the live ones showing they were so only when prodded considerably, their movements even then being very sluggish. None of the dead worms had begun to decompose. The temperature of the incubator was shown by the thermometers to have ranged from 52° to 66° F. during the test. The temperature of the water in the cans kept in it was 57° F. at the end of the test, and had probably averaged a little under 60°. The temperature in the barrel had ranged from 31° to 39½° F., that of the water in the pail being 35° at the end of the test.

This incubator and pail experiment was duplicated by a test carried out similarly in all details, except that vaseline bottles of 3½-ounce capacity, with tightly inserted cork stoppers, were used instead of the cans, the cocoons being submerged at noon, Jan. 29, 1917, and being taken from the water at 3 P.M., February 13. Of the 30 worms kept in the incubator 16 were dead and 14 alive at the end of the test, while of the 30 tested in the pail 27 were alive and only 3 dead. Moreover, the live worms from the bottles in the pail were much more active after they got warmed up than were those from the incubator. None of the dead worms had begun to decompose noticeably. In this test the temperature in the barrel ranged from 32° to 36° F. The incubator got out of order twice, — on the seventh and tenth days of the test, — its temperature the first time falling to 40° and the second to 33° F. With these exceptions it ran between 52° and 62°, and probably averaged about 56°.

Many of the cocoons used in these tests were carefully opened under water at the end of the submergence, and, while they were all found to be largely filled with water, none were without a little air or gas, this indicating that the findings in this regard previously reported by the writer[1] were not quite accurate, the former examinations apparently not having been sufficiently careful.

The results of these experiments seem to prove that the effect of submergence of the worms in their cocoons depends largely, if not principally, upon the temperature of the water, and they suggest that a flowage after picking, if it is begun before October 1 and continued for twelve or possibly even ten days, may control this insect as well as late holding of the winter-flowage usually does. It may be said that such a flooding would interfere with harvesting, but as late picking is usually a result of late holding of the previous winter-flowage, and as late holding is most commonly practiced as a treatment for the fruit worm, this objection does not seem valid. Flooding practiced annually after picking would probably have a much less harmful effect on a bog than late holding of the winter-flowage every year has.

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[1] Bul. No. 160, Mass. Agr. Expt. Sta., 1915, p. 113.

BOG MANAGEMENT.

Prof. H. B. Scammell has recently reported [1] a destructive visitation of the fall army worm (*Laphygma frugiperda* S. & A.) this year on widely separated cranberry bogs in New Jersey following closely, and evidently somehow caused by, the removal of the winter-flowage in mid-July. This insect feeds on a variety of plants, but has not heretofore been known as a cranberry pest. As its frequent outbreaks, which start in the southern States, sometimes reach as far north as Canada, by the spreading of the successive broods of strong-flying moths, in a single season, though it is unable to endure the winter in the north, there is ground for fearing that midsummer removal of the winter-flowage may more or less regularly invite serious trouble from this insect on Cape Cod as well as in New Jersey. This unexpected development must be regarded as a possible complication in connection with certain phases of the biennial cropping system suggested by the writer in last year's report (page 46).

Late holding of a deep winter-flowage is sometimes dangerous. This flowage was started off from a bog in Assonet, Mass., on June 10, its withdrawal being completed on the 11th. When the writer visited this bog on June 30 the vines seemed completely dead where the flowage had been deepest (5 feet deep), whereas they showed no injury, aside from the retarded seasonal development of growth, where the water had been shallowest (2 feet deep), their leaves having been well retained and appearing green and healthy. Where the water had been deepest the leaves were all off, the buds at the tips of the uprights were gone, and the vines were brittle and showed no green in the break when broken off. There was a complete gradation from this condition to that where the flowage had been shallowest, corresponding with the variation in elevation.

Part of the vines on this bog were set out in the spring of 1914, and part in the spring of 1915, strips of both plantings running from the lowest to the highest parts of the bog. The writer is informed by the manager that the one-year sets where the flowage was deep finally recovered somewhat, but that the two-year plantings were killed entirely.

A large bog in Rochester, Mass., the winter-flowage of which ranged in depth from 4 feet to nothing, had this flowage held until May 31 this season. This is an old bog, with vines well established. Where the water was deepest the leaves all came off, leaving the uprights alive but bearing only the terminal bud. On the other hand, there was no abnormal falling of the leaves where the water was shallow. As on the Assonet bog, there was a complete gradation in the injury corresponding with the variation in the depth of the flowage.

A new 60-acre bog at Assonet, Mass., was flowed on the night of May 31, the vines being completely submerged for forty-eight hours, the water ranging from 3 feet to a few inches in depth, and averaging about 2½ feet.

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[1] Proc. 47th Ann. Meet. of the Amer. Cranb. Grow. Assoc. p. 11, January, 1917.

The flooding and draining were done entirely at night. A few days later the writer's attention was called to an injury that had resulted. He visited the bog and found the buds and even the tops of the new growth of the uprights on parts of it seriously hurt. The injury was mainly on the central portion of the bog, and centered around a large pile of ashes left from the burning of stumps and brush when it was built. Vines at considerable distances from this pile showed at most but slight injury, except in a streak parallel to the end of the dike toward which the wind had blown during the flooding. Leaves of bushes which had hung down into or stood in the water of the reflow, around the margin of the bog, showed a marked and unusual burning injury, and they bore traces of a white powder which appeared to be ash that had floated in the water from the pile at the center of the bog. The situation as a whole led all those who observed it to conclude that the ash pile had caused the trouble. The pile was estimated to be 2½ feet deep over an area 25 feet square and about 6 inches deep over another area 75 feet square. Piles of ashes on bogs are probably dangerous because of the lye leached from them. Many unaccountable spots where vines refuse to grow thriftily on bogs may be the result of effects remaining from ashes left from the burning of brush piles. It is well known that alkalies in the soil are inimical to cranberry growth.

A portable sectional bridge devised by the writer for use in carting berries across bog ditches proved valuable at the station bog this year. With its help it was easy to cart berries without killing the vines in tracks by repeated passages of the wheels over the same ground. A light truck probably could be used to great advantage with this bridge, though the writer has tried only a horse and wagon with it so far. At any rate, it will make it possible to much reduce the present expense of removing berries from bogs. It may be seen at the station bog at any time during the cranberry season.

With many Cape Cod bogs a desirable reduction in the cost of resanding could probably be effected by the development of a sanding rim around the margin. With such a rim the sand for any part of the bog could always be brought from the nearest point. The rim should be wide enough for a good roadway, and it should be built level with the bog surface, so that it may serve as a sanitary catch-basin for floating berries and leaves. If, as the results of some of the writer's storage experiments seem to indicate, the berries from the marginal portion of a bog, other conditions being the same, are usually of poorer keeping quality than those from the center, the condition may naturally be laid to the continual deposition of diseased cranberry material floating on the surface of repeated flowages and wafted to the margin by the wind. Thus the possible value of a marginal catch-basin as suggested becomes evident. The sanding rim would also have some value as fire protection for a bog.

As the sanding rim becomes sufficiently widened by the removal of sand in repeated resandings, the bog can be gradually enlarged by planting on the inner side of the rim, this increase in property being mostly clear gain.

The sanding rim can be constructed most advantageously when a bog is built. Its development after the bog is planted is attended with some difficulties. Among these the extra cost of turfing the upland adjacent to the bog, and the liability in resanding of seeding the bog more or less with certain troublesome weeds, should be especially considered.

OBSERVATIONS ON THE SPOILAGE OF CRANBERRIES DUE TO LACK OF PROPER VENTILATION.

BY C. L. SHEAR AND NEIL E. STEVENS, PATHOLOGISTS, AND B. A. RUDOLPH, SCIENTIFIC ASSISTANT, FRUIT-DISEASE INVESTIGATIONS, BUREAU OF PLANT INDUSTRY.

INTRODUCTION.

The injury to cranberries due to keeping them in tightly closed packages was brought strikingly to the writers' attention during temperature tests conducted in the fall of 1916. Uniform samples of Early Black cranberries from bogs near Wareham, Mass., were put up in pound coffee cans and sent to Washington by mail. There they were placed in the constant temperature apparatus used by Drs. Brooks and Cooley of this office, and described by them in their recent paper.[1]

One can from each lot was placed at each of the following temperatures: Centigrade, 0, 5, 10, 15 and 20 degrees (equal to 32, 41, 50, 59 and 68 degrees Fahrenheit). They were kept at these temperatures from early in September until about the middle of November. When the berries were removed from the cans and sorted, it was found that spoilage at the lower temperatures had been much greater than the previous experience of the writers had led them to believe could be due to fungi alone. Many of the spoiled berries had a peculiar lusterless appearance, and were of a uniform dull red color differing both from normal and from typical rotten berries.

Among various factors considered as possible causes of this condition the excessive accumulation of carbon dioxide seemed the most probable. The work of F. W. Morse,[2] Gore [3] and others has proven that large amounts of this gas are given off in the respiration of various fruits, while the studies of Fulton [4] indicate that the spoiling of strawberries and raspberries which he noted in tight packages is due to the accumulation of carbon dioxide. Fulton found that if strawberries were kept in tightly closed bottles for three days the oxygen of the air was practically exhausted, and more than 35 per cent. by volume of carbon dioxide had accumulated. Under these conditions, as well as in cartons tightly wrapped, "The fruit softened and had the characteristic bad flavor of fruit confined in an atmosphere of carbon dioxide" (3, p. 22).

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[1] Brooks, Charles, and Cooley, J. S.: Temperature Relations of Apple-rot Fungi. Journal of Agricultural Research, 8, 139-163, 1917.

[2] Morse, Fred W.: Effect of Temperature on the Respiration of Apples. Jour. Amer. Chem. Soc., 30, 876-881, 1908.

[3] Gore, H. C.: Studies on Fruit Respiration, U. S. Dept. Agr., Bur. of Chem., Bul. No. 142, 1911.

[4] Fulton, S. H.: The Cold Storage of Small Fruits, U. S. Dept. Agr., Bur. of Plant Indus., Bul. No. 108, 1907.

Dr. Charles Brooks and Dr. E. M. Harvey of this office, who have separately studied storage conditions in apples and other fruits, examined the cranberries referred to and were of the opinion that the condition might very likely be due to the accumulation of an excessive amount of carbon dioxide. Although it was then too late in the season (November 20) to undertake a thorough investigation of the subject, preliminary tests were made which gave results of considerable interest.

TEMPERATURE TESTS IN OPEN AND CLOSED CANS.

In order to compare directly the keeping of cranberries in open and closed cans, uniform lots of sound berries were divided, one portion being placed in tightly closed cans, and the other portion in similar cans with the covers removed. The result of one of these tests, which is typical of several, is given in the following tables: —

Temperature Tests on Howes from State Bog, Massachusetts, beginning November 21, ending December 16.

Closed Cans.

TEMPERATURE IN DEGREES C.	Sound.	Spoiled.	Spoiled (Per Cent.).
20,	328	172	34.5
15,	357	147	29.5
10,	444	67	13.0
5,	472	29	5.5
0,	483	20	4.0

Open Cans.

TEMPERATURE IN DEGREES C.	Sound.	Spoiled.	Spoiled (Per Cent.).
20,	291	69	19.0
15,	333	61	15.5
10,	333	29	8.0
5,	341	18	5.0
0,	340	8	2.5

It will be noted that in all cases the amount of spoilage is greater in the closed cans than in the open cans.

EFFECT OF CARBON DIOXIDE ON CRANBERRIES.

Several series of tests were made in which cranberries from various sources (Early Blacks and Howes from Massachusetts, and Howes from New Jersey) were kept for short periods in an atmosphere of nearly pure carbon dioxide. It was noticed in each case that at the end of three days practically all the berries in the carbon dioxide were spoiled, whereas berries from the same lots kept in similar containers with air showed very little rot even at the end of two weeks.

The berries which had been kept in an atmosphere of carbon dioxide had the peculiar uniform dull, lusterless, red color which had been noticed in many of the berries which had spoiled in closed cans. On sectioning these berries it was found that the tissue of the berry, which is white in a normal berry, had taken on the same uniform red color. Berries which have been treated in this manner have a peculiar, bitter taste, which is very characteristic. They are no longer firm, as in the sound fruit, nor elastic to the touch as in rotten fruit, but have become flaccid. The same effect on the berries was readily produced by sealing up a quantity in an air-tight container, and allowing them to remain at room temperature for a week.

That this injurious effect is produced by the accumulation of carbon dioxide is indicated by preliminary tests made in December, 1916. Equal quantities of sound Early Blacks or Howes were put in similar containers (Hempel desiccators). One of these desiccators was filled with carbon dioxide, the other two contained air, but the upper portion of one of them was filled with a saturated solution of potassium hydroxide, which would absorb the carbon dioxide almost as fast as given off by the berries. The berries in the first lot were thus exposed to an atmosphere of carbon dioxide throughout the test; those in the second lot were exposed to air containing practically no carbon dioxide; and those in the third to an atmosphere in which the carbon dioxide given off in respiration was allowed to accumulate. The results of one of these tests which was typical of all are given in the following table: —

CONDITIONS UNDER WHICH BERRIES WERE KEPT.	CONDITION OF BERRIES AT END OF TEST.		
	Sound.	Spoiled.	Spoiled (Per Cent.).
CO_2,	35	34	50
Air exposed to water,	56	39	40
Air exposed to KOH solution,	45	19	29

It will be noted that the amount of spoilage, including rot due to fungi, is greatest in the berries exposed to carbon dioxide and least in the container from which this gas was removed, which apparently indicates that a large portion of the spoilage was due to the carbon dioxide.

Effect of Different relative Humidities on Spoilage due to Carbon Dioxide.

Most of the tests described above had been made in atmospheres having relatively high moisture content. In order to determine whether the humidity of the air in any way influenced the spoilage, a series of tests was run in which sound cranberries of the Howes variety were kept in tightly sealed Hempel desiccators which were maintained at constant humidity by sulfuric acid solutions of different densities. This method has been described by one of the writers in an earlier paper.[1] All these tests were made at a temperature of about 24° C.

Chambers having relative humidities of 100 per cent. (saturated atmosphere), 75 per cent., 50 per cent., 25 per cent. and approximately 0 per cent. were used, and so far as could be detected by careful observation there was no difference in the rate of spoilage at the different humidities.

Relation of Fungi to Spoilage due to Carbon Dioxide.

It is of course possible that one effect of accumulation of carbon dioxide, at least in small amounts, may be to make the berries more susceptible to the attacks of fungi. It seems certain, however, that the injury to the fruit is in many cases wholly independent of the action of fungi.

On March 13, 1917, we received from Dr. Franklin a box of Pride cranberries taken from a crate of fruit which had been kept in storage in the basement of the screenhouse at the State experimental bog at East Wareham. These were taken to represent the average condition of the spoiled fruit at the time. This lot contained 271 berries. They were carefully sorted, and 195 were somewhat softened and flaccid, having much less resiliency than the rotten fruit, in which the tissues are more or less destroyed by the growth of fungi. They had the same general appearance as berries treated with carbon dioxide, and their condition was believed to be due to the time and manner in which they had been kept rather than to fungous disease. Fifty of these berries were taken at random and cultures made by transplanting the bulk of the pulp from the cranberries, the skin being removed. Of these cultures, but 2, or 4 per cent., produced fungi. Assuming that this represents the average number affected with fungous disease, deducting 4 per cent. from the total, 195, would leave 187 presumably free from fungous disease. Cultures were also made from the tissue of the remaining 76, which had more the appearance and character of fruit attacked by fungi. The results of these cultures showed, however, that 49 of these berries were apparently destroyed by some other cause than fungous disease, thus making a total of 236 out of 271, or 87 per cent., not destroyed by fungi but presumably by the period and conditions of storage since picking.

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[1] Stevens, Neil E.: A Method for studying the Humidity Relations of Fungi in Culture. Phytopathology, 6, 428–432, 1916.

From a sample of cranberries of the cherry variety taken July 2, 1917, at Madrid, Me., which had been kept in the cellar of a house all winter, 50 softened berries were chosen at random and cultures were made from their pulp, as described above. Twenty of these berries, or 40 per cent., yielded the end-rot fungus, while 22 berries, or 44 per cent., showed no fungi, and were presumably destroyed by the other causes discussed in this paper.

EFFECT OF CARBON DIOXIDE ON FUNGI IN THE BERRIES.

That carbon dioxide in high concentrations injures fungi in the cranberries as well as the berries themselves is indicated by a test in which equal numbers of rotten cranberries from a single lot were placed in similar vessels, one of which was filled with carbon dioxide and the other left open. At the end of one week transfers of tissue were made from each berry. Of the berries which had been kept in an atmosphere of carbon dioxide 70 per cent. contained no viable fungi and the others yielded *Penicillium*, or the end-rot fungus. Of the berries kept in the open vessel only 15 per cent. contained no living fungi, and the others yielded fungi of six different species.

The rate at which carbon dioxide is given off by cranberries in storage and the variation of this rate with temperature, the concentration of the gas necessary to cause injury, and the concentration which occurs under storage conditions, have not been determined, and further investigations on this line are planned. It seems very probable from the facts now in hand, however, that this spoilage is a considerable factor in the loss during storage, and throws new light on the results of Dr. Franklin, [1] which indicate the importance of ventilation, as well as on this year's results in shipping cranberries in tight as compared with ventilated packages.

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[1] Franklin, H. J.: Report of Cranberry Substation for 1915, Mass. Agr. Expt. Sta., Bul. No. 168, 1916.

BULLETIN No. 181 NOVEMBER, 1917

MASSACHUSETTS AGRICULTURAL EXPERIMENT STATION

DIGESTION EXPERIMENTS WITH SHEEP

By J. B. LINDSEY, C. L. BEALS and P. H. SMITH

The complete data of one hundred and fifty-three digestion experiments with sheep, together with short discussions of each, are contained in this bulletin. Complete summaries and averages are given in the latter part of the publication for the convenience of the reader.

The bulletin is not intended for general distribution, as it is of a technical character; it will prove of most use to experiment station workers and others interested in determining the relative values of feeding stuffs.

Requests for bulletins should be addressed to the
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[1] On leave on account of military service.
[2] On leave.

PUBLICATION OF THIS DOCUMENT
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BULLETIN No. 181.

DEPARTMENT OF CHEMISTRY.

DIGESTION EXPERIMENTS WITH SHEEP.

J. B. LINDSEY, C. L. BEALS AND P. H. SMITH.[1]

INTRODUCTION.

The digestion experiments reported in this bulletin were made during a number of years, beginning with the autumn of 1912. They include portions of Series XVIII. and XIX. and all of Series XX., XXI. and XXII., with the exception of one experiment in Series XXII. Each series includes a period of time between the early autumn and the following spring. A few of the results have been given in other publications.

The basal ration in the majority of cases was English hay, or English hay and gluten feed.

The usual method of conducting the tests was employed, and has been fully described elsewhere.[2]

The composition of the feeds tested in the several series is presented in the tabulation known as Table I., which is arranged alphabetically.

Table II. is arranged by series, beginning with Series XVIII. It contains the average amount of feces excreted daily by each sheep, the weight of one-tenth of the feces in air-dry condition, the percentage of dry matter in the air-dry feces, and the composition of the dry matter.

Table III. contains the weight of the animals at the beginning and end of each digestion period, and the average amount of water consumed daily.

In Table IV. will be found the digestion coefficients of *basal rations* used in the computations which follow in Table V. This table, headed "Computation of Digestion Coefficients," presents the detailed data of each trial, together with the resulting coefficients. Following the complete data will be found a summary of the coefficients secured for each material, together with a discussion of the results.

Table VI. gives an average of the coefficients secured for each feed tested.

It may be stated that the period in nearly all cases extended over fourteen days, the first seven of which were preliminary, the collecting of the feces being made on the last seven. Ten grams of salt were fed each sheep daily, and water *ad libitum*. The sheep were grade Shropshires, as nearly as possible of the same age and weight.

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[1] Mr. Smith and Mr. Beals did the larger part of the analytical work and the tabulations; the work at the feeding barn was carried out by Mr. J. R. Alcock.

[2] Eleventh report of the Mass. State Agri. Exp. Sta., pp. 146–149 (1893).

TABLE I. — COMPOSITION OF FEEDSTUFFS (PER CENT.) (ARRANGED ALPHABETICALLY).

Series.	Period.	Feeds.	Dry Matter as weighed out.	Dry Matter Basis.				
				Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
XXII.	12	Alfalfa (third cutting, fine quality),	87.62	6.03	15.11	35.42	41.53	1.91
XXII.	14	Alfalfa (third cutting, fine quality),	91.25	6.95	15.57	34.70	40.72	2.06
XVIII.	4	Cabbage (heads),	9.66	8.22	17.98	9.84	62.77	1.19
XVIII.	5	Cabbage (leaves),	19.05	14.49	11.94	13.12	58.04	2.41
XIX.	7	Cabbage (whole),	11.73	12.20	21.82	10.30	53.76	1.92
XIX.	8	Carrots,	12.54	8.56	8.00	8.25	74.04	1.15
XX.	8	Carrots,	13.13	10.31	11.23	8.83	68.61	1.02
XX.	9	Carrots,	11.40	9.81	11.11	8.50	69.49	1.09
XIX.	13	Corn bran,	90.42	.86	5.22	14.50	78.15	1.27
XXI.	7	Corn bran,	90.24	1.30	8.52	13.21	74.52	2.45
XIX.	12	Distillers' grains (corn),	93.86	1.83	29.45	12.62	46.20	9.90
XXI.	6	Distillers' grains (corn),	96.87	2.31	26.40	14.71	47.18	9.40
XXI.	12	Feterita,	89.59	1.80	13.23	1.40	80.23	3.34
XIX.	2	Gluten feed,	89.55	1.05	27.84	8.75	57.78	4.58
XIX.	5	Gluten feed,	89.93	1.11	26.96	8.70	59.29	3.94
XIX.	14	Gluten feed,	90.52	.95	27.93	9.32	56.86	4.94
XIX.	15	Gluten feed,	90.87	2.30	25.84	8.17	58.95	4.74

XX.	3	Gluten feed,	91.10	1.84	25.55	8.27	59.69	4.65
XX.	4	Gluten feed,	91.72	2.03	25.85	8.26	59.22	4.64
XX.	5	Gluten feed,	91.14	1.95	26.73	8.33	58.39	4.60
XX.	9	Gluten feed,	91.35	2.21	26.57	7.76	58.65	4.81
XX.	11	Gluten feed,	91.45	2.16	25.47	8.37	59.38	4.62
XX.	13	Gluten feed,	91.80	2.15	25.84	8.21	59.35	4.45
XX.	14	Gluten feed,	92.09	2.13	27.11	8.55	57.72	4.49
XXI.	1	Gluten feed,	90.32	3.36	28.29	7.43	59.11	1.81
XXI.	3	Gluten feed,	90.44	3.49	28.05	7 30	59.37	1.79
XXI.	8	Gluten feed,	91.05	3 42	27.86	7.30	59.69	1.73
XXI.	11	Gluten feed,	91.54	3.37	28.09	7.65	59.06	1.83
XXI.	12	Gluten feed,	91.50	3.41	27.94	7.39	59.70	1.56
XIX.	10	Gluten meal (Diamond),	94.40	.86	44.99	2.16	50.18	1.81
XIX.	11	Gluten meal (Diamond),	93 80	1.14	44.79	1.84	50.21	2.02
XIX.	12	Gluten meal (Diamond),	94.01	1.34	44.99	2.01	49.73	1.93
XXI.	5	Gluten meal (Diamond),	90.97	1.13	45.14	2.06	49.97	1.70
XXI.	6	Gluten meal (Diamond),	91.06	1.16	45.12	2.23	49.62	1.87
XXI.	7	Gluten meal (Diamond),	91.55	.96	44.58	2.02	50.79	1.65
XVIII.	3	Hay (English),	86.75	5.67	9.87	31.56	50.21	2.69
XVIII.	4	Hay (English),	89.35	5.26	9.25	31 33	51.50	2.66
XVIII.	5	Hay (English),	88.80	5.72	9.47	31.48	50.42	2.91
XVIII.	6	Hay (English),	88.92	6.53	9 39	32.35	49.11	2.62

TABLE I. — COMPOSITION OF FEEDSTUFFS (PER CENT.) (ARRANGED ALPHABETICALLY) — *Continued.*

Series.	Period.	FEEDS.	Dry Matter as weighed out.	DRY MATTER BASIS.				
				Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
XVIII.	7	Hay (English),	89.07	6.49	9.32	31.27	50.25	2.67
XIX.	2	Hay (English),	88.02	5.83	9.52	31.40	50.98	2.27
XIX.	3	Hay (English),	87.00	5.86	9.45	30.94	51.51	2.24
XIX.	4	Hay (English),	87.47	5.91	9.42	31.48	50.77	2.42
XIX.	5	Hay (English),	88.05	5.81	9.43	31.70	50.78	2.28
XIX.	6	Hay (English),	87.87	5.55	9.00	31.34	51.42	2.69
XIX.	7	Hay (English),	88.57	5.56	8.15	31.83	52.04	2.42
XIX.	8	Hay (English),	88.75	5.73	8.13	34.66	49.22	2.26
XIX.	9	Hay (English),	88.75	5.74	8.52	31.22	51.20	3.32
XIX.	10	Hay (English),	90.27	5.76	7.57	32.07	52.27	2.33
XIX.	11	Hay (English),	92.35	5.66	7.02	32.07	52.89	2.36
XIX.	12	Hay (English),	89.75	6.05	7.36	32.06	51.53	3.00
XIX.	13	Hay (English),	90.87	6.13	7.02	32.83	51.78	2.24
XIX.	14	Hay (English),	89.95	6.01	8.29	31.55	51.47	2.68
XIX.	15	Hay (English),	90.42	5.72	7.53	31.48	53.07	2.20
XX.	1	Hay (English),	92.17	6.01	7.22	32.43	51.80	2.54
XX.	2	Hay (English),	89.90	6.22	6.82	32.28	51.53	3.15

XX.	3	Hay (English),	90.00	6.09	7.32	32.14	51.91	2.54
XX.	4	Hay (English),	90.55	6.09	7.35	32.43	51.16	2.97
XX.	5	Hay (English),	90.52	6.01	8.68	31.98	50.54	2.79
XX.	6	Hay (English),	89.73	6.16	7.44	32.08	51.96	2.36
XX.	7	Hay (English),	91.92	6.09	7.33	32.69	51.54	2.35
XX.	8	Hay (English),	89.79	6.72	7.94	32.53	50.23	2.58
XX.	9	Hay (English),	90.37	6.23	7.60	30.44	53.06	2.67
XX.	10	Hay (English),	91.00	6.53	8.15	32.02	50.80	2.50
XX.	11	Hay (English),	91.07	6.80	8.57	32.14	49.99	2.50
XX.	12	Hay (English),	92.45	6.67	7.17	31.32	52.10	2.74
XX.	13	Hay (English),	92.02	6.40	7.30	32.22	51.61	2.47
XX.	14	Hay (English),	92.62	6.27	6.95	32.44	51.75	2.59
XXI.	1	Hay (English),	89.35	6.91	7.55	32.06	50.65	2.83
XXI.	2	Hay (English),	89.12	6.74	7.59	32.26	50.54	2.87
XXI.	3	Hay (English),	88.40	6.68	7.51	32.54	50.40	2.87
XXI.	4	Hay (English),	88.85	6.59	7.59	32.67	50.29	2.86
XXI.	5	Hay (English),	89.87	6.87	7.43	33.77	49.31	2.62
XXI.	6	Hay (English),	89.75	6.65	7.47	33.21	50.26	2.41
XXI.	7	Hay (English),	90.47	6.78	7.09	32.13	51.60	2.40
XXI.	8	Hay (English),	90.52	6.96	7.27	33.73	49.41	2.63
XXI.	9	Hay (English),	88.90	7.06	7.49	32.37	50.41	2.67
XXI.	10	Hay (English),	89.37	6.93	7.31	32.91	50.24	2.61

TABLE I. — COMPOSITION OF FEEDSTUFFS (PER CENT.) (ARRANGED ALPHABETICALLY) — *Continued.*

Series.	Period.	FEEDS.	Dry Matter as weighed out.	DRY MATTER BASIS.				
				Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
XXI.	11	Hay (English),	90.80	8.54	10.20	30.49	48.06	2.71
XXI.	12	Hay (English),	90.17	8.46	9.65	30.57	48.59	2.73
XXI.	13	Hay (English),	90.65	8.27	9.12	31.06	48.83	2.72
XXI.	14	Hay (English),	88.43	8.10	9.03	31.24	48.89	2.74
XXII.	1	Hay (English),	86.70	7.71	9.17	30.29	50.30	2.53
XXII.	2	Hay (English),	85.67	7.59	8.65	31.93	49.28	2.55
XXII.	3	Hay (English),	88.25	8.06	9.47	30.45	49.47	2.55
XXII.	5	Hay (English),	89.00	7.55	9.43	31.12	49.66	2.24
XXII.	8	Hay (English),	89.92	6.85	8.25	32.89	49.66	2.35
XXII.	9	Hay (English),	90.13	7.18	8.37	33.80	48.25	2.40
XXII.	10	Hay (English),	90.00	7.32	8.70	32.16	49.36	2.46
XXII.	11	Hay (English),	90.75	6.75	8.23	32.97	49.58	2.47
XXII.	13	Hay (English),	90.87	7.19	8.14	33.26	49.02	2.39
XXII.	16	Hay (English),	89.87	7.21	9.06	30.33	50.64	2.76
XXII.	17	Hay (English),	88.07	7.01	8.74	33.39	48.05	2.81
XVIII.	3	Mangels,	16.43	5.93	5.26	5.96	82.57	.28
XVIII.	6	Mangels,	17.38	6.28	6.42	6.81	80.23	.26

XX.	11	New Bedford pig meal,	91.20	19.65	23.59	9.15	44.30	3.31
XXI.	8	New Bedford garbage tankage,	91.47	15.72	22.02	9.67	50.92	1.67
XIX.	4	Pumpkins (seeds removed),	5.42	8.81	13.74	17.33	57.56	2.56
XIX.	6	Pumpkins (entire),	8.81	7.60	17.72	16.86	43.14	14.68
XX.	2	Pumpkins (entire),	13.42	7.80	14.17	13.01	54.26	10.76
XX.	3	Pumpkins (entire),	15.92	7.26	15.67	14.39	51.77	10.91
XX.	4	Pumpkins (entire),	11.72	8.31	14.85	15.73	48.31	12.80
XXII.	15	Rowen,	90.87	8.12	13.03	28.15	47.29	3.41
XX.	7	Soy bean hay,	88.27	6.63	15.86	34.88	40.56	2.07
XIX.	10	Starch (potato),	90.58	–	–	–	100.00	–
XIX.	11	Starch (potato),	90.24	–	–	–	100.00	–
XIX.	12	Starch (potato),	90.79	–	–	–	100.00	–
XXI.	5	Starch (potato),	89.56	–	–	–	100.00	–
XXI.	6	Starch (potato),	90.27	–	–	–	100.00	–
XXI.	7	Starch (potato),	87.82	–	–	–	100.00	–
XXII.	11	Stevens' "44" Dairy Ration,	91.06	4.17	26.95	12.88	49.56	6.44
XXII.	1	Sudan grass (green),	23.50	6.50	11.78	27.87	50.71	3.14
XXII.	3	Sudan grass (dry),	78.12	8.59	13.57	33.28	42.93	1.63
XXII.	4	Sudan grass (dry),	88.00	7.37	11.89	35.79	43.51	1.44
XXII.	6	Sudan grass (dry),	88.07	9.67	15.49	33.32	39.99	1.53
XXII.	7	Sudan grass (dry),	87.92	10.07	14.45	33.20	40.74	1.54
XXII.	17	Sudan grass (green),	19.58	7.18	14.23	30.33	43.55	4.71

TABLE I. — COMPOSITION OF FEEDSTUFFS (PER CENT.) (ARRANGED ALPHABETICALLY) — *Concluded.*

Series.	Period.	FEEDS.	Dry Matter as weighed out.	DRY MATTER BASIS.				
				Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
XXI.	14	Sweet clover,	16.55	9.56	17.33	33.80	36.45	2.86
XXII.	16	Sweet clover,	14.50	4.60	21.46	26.78	43.76	3.40
XVIII.	7	Turnips (Swedish),	13.79	7.33	9.58	10.99	71.31	.79
XX.	12	Wheat gluten (high grade) flour,	91.66	.86	92.41	.11	6.23	.39
XXI.	4	Wheat gluten (high grade) flour,	92.96	.77	92.84	.07	5.91	.41
XXI.	10	Wheat gluten (high grade) flour,	94.96	.88	89.19	.09	8.18	1.66
XIX.	5	Vegetable ivory meal,	87.36	1.37	6.02	7.02	84.90	.69
XX.	13	Vegetable ivory meal,	91.25	1.19	4.72	8.27	85.05	.77
XXI.	3	Vegetable ivory meal,	89.10	1.19	5.33	8.75	83.17	1.56
XXII.	9	Vinegar grains (Fleischmann's),	92.22	2.51	20.56	20.13	50.32	6.48
XXII.	10	Vinegar grains (Fleischmann's),	92.53	2.57	20.22	20.12	50.34	6.75

TABLE II. — COMPOSITION OF FECES (PER CENT.).

Series.	Period.	Sheep.	FEEDS.	Average Daily Feces (Grams).	One-tenth Feces Air-dry (Grams).	Dry Matter in Air-dry Feces.	DRY MATTER BASIS.				
							Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
XVIII.	3	V.	English hay and mangels,	371	15.994	94.67	15.84	12.59	23.56	43.20	4.81
XVIII.	3	VI.	English hay and mangels,	339	15.550	94.67	14.76	12.13	24.20	43.81	5.10
XVIII.	4	I.	English hay and cabbage (heads),	286	13.190	95.03	12.32	13.63	23.79	46.01	4.25
XVIII.	4	II.	English hay and cabbage (heads),	274	13.819	95.20	12.37	12.65	25.56	45.07	4.35
XVIII.	5	I.	English hay and cabbage (leaves),	377	18.623	95.19	18.05	12.53	22.20	42.78	4.44
XVIII.	5	II.	English hay and cabbage (leaves),	414	19.950	95.10	17.11	12.54	21.51	44.23	4.61
XVIII.	6	V.	English hay and mangels,	388	17.945	94.78	14.15	12.97	23.63	43.63	5.62
XVIII.	6	VI.	English hay and mangels,	364	17.344	94.87	13.31	11.62	24.98	44.68	5.41
XVIII.	7	V.	English hay and turnips (Swedish),	331	15.648	95.29	13.18	12.00	26.59	44.29	3.94
XVIII.	7	VI.	English hay and turnips (Swedish),	310	15.575	95.40	13.69	10.51	28.74	43.32	3.74
XIX.	2	V.	English hay and gluten feed,	470	22.650	92.47	9.25	12.79	27.62	46.75	3.59
XIX.	2	VI.	English hay and gluten feed,	465	22.300	92.59	10.47	12.62	26.49	46.81	3.61
XIX.	3	I.	English hay,	691	29.619	94.53	11.57	11.96	27.04	46.00	3.43
XIX.	3	II.	English hay,	653	31.510	93.55	10.53	10.46	30.00	45.74	3.27
XIX.	4	I.	English hay and pumpkins (seeds removed),	362	18.047	93.81	11.62	12.58	26.74	45.21	3.85
XIX.	4	II.	English hay and pumpkins (seeds removed),	380	19.805	93.91	12.92	11.34	28.62	43.35	3.77

TABLE II. — COMPOSITION OF FECES (PER CENT.) — *Continued.*

Series.	Period.	Sheep.	FEEDS.	Average Daily Feces (Grams).	One-tenth Feces Air-dry (Grams).	Dry Matter in Air-dry Feces.	DRY MATTER BASIS.				
							Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
XIX.	5	V.	English hay, gluten feed and vegetable ivory meal,	589	25.210	94.30	9.16	15.60	25.96	45.32	3.96
XIX.	5	VI.	English hay, gluten feed and vegetable ivory meal,	508	24.191	94.50	9.80	14.70	25.34	46.72	3.44
XIX.	6	I.	English hay and pumpkins (entire),	554	25.333	95.00	10.65	12.68	28.88	44.04	3.75
XIX.	6	II.	English hay and pumpkins (entire),	456	22.869	94.87	11.87	12.60	28.40	43.04	4.09
XIX.	7	I.	English hay and cabbage (whole),	415	19.277	95.14	14.45	12.12	25.28	44.32	3.83
XIX.	7	II.	English hay and cabbage (whole),	386	20.009	94.93	14.62	11.04	28.18	42.41	3.75
XIX.	8	I.	English hay and carrots,	503	21.146	95.74	15.09	12.30	26.42	42.90	3.29
XIX.	8	II.	English hay and carrots,	411	19.484	95.87	15.24	11.25	26.75	43.33	3.43
XIX.	9	V.	English hay,	688	29.467	95.01	9.68	10.04	29.04	47.66	3.58
XIX.	9	VI.	English hay,	674	31.710	95.10	9.08	9.81	30.39	47.20	3.52
XIX.	10	III.	English hay, potato starch and gluten meal,	268	13.241	95.92	8.57	13.15	28.26	45.87	4.15
XIX.	10	IV.	English hay, potato starch and gluten meal,	328	14.744	95.81	10.08	12.92	28.06	45.12	3.82
XIX.	11	IV.	English hay, potato starch and gluten meal,	408	17.432	95.71	8.81	11.75	28.39	47.53	3.52
XIX.	12	IV.	English hay, potato starch, gluten meal and distillers' grains,	627	24.066	95.33	8.87	13.60	28.61	45.36	3.56
XIX.	13	I.	English hay and corn bran,	451	19.102	94.45	7.97	11.54	25.16	51.97	3.36
XIX.	13	II.	English hay and corn bran,	485	23.441	94.50	7.47	11.16	27.33	50.75	3.27
XIX.	14	V.	English hay and gluten feed,	539	23.730	94.06	9.17	13.01	26.06	47.47	4.29

XIX.	14	VI.	English hay and gluten feed,	566	26.221	94.22	8.70	11.00	28.28	47.97	4.05
XIX.	15	V.	English hay and gluten feed,	543	24.694	94.56	8.94	11.28	27.99	48.20	3.59
XIX.	15	VI.	English hay and gluten feed,	737	28.006	94.60	8.21	11.20	29.08	47.93	3.58
XX.	1	I.	English hay,	598	28.127	92.55	10.27	10.05	27.18	48.47	3.76
XX.	1	II.	English hay,	620	29.139	92.54	10.36	9.80	28.09	48.07	3.68
XX.	2	I.	English hay and pumpkins (entire),	486	22.314	94.62	11.09	12.80	27.06	44.09	4.96
XX.	2	II.	English hay and pumpkins (entire),	490	20.370	94.95	12.97	12.34	26.22	43.43	5.04
XX.	3	I.	English hay, gluten feed and pumpkins (entire),	577	24.890	94.94	10.84	12.91	26.26	45.85	4.14
XX.	3	II.	English hay, gluten feed and pumpkins (entire),	685	25.564	94.97	11.61	12.70	25.74	45.63	4.32
XX.	4	I.	English hay, gluten feed and pumpkins (entire),	486	21.687	94.42	10.07	13.77	28.78	43.36	4.02
XX.	4	II.	English hay, gluten feed and pumpkins (entire),	684	24.688	95.02	9.72	12.82	29.32	43.70	4.44
XX.	5	I.	English hay and gluten feed,	568	19.754	95.28	10.20	14.22	23.46	47.89	4.23
XX.	5	II.	English hay and gluten feed,	601	22.118	95.56	10.97	14.56	24.54	45.95	3.98
XX.	6	IV.	English hay,	644	30.050	95.95	8.89	9.57	29.47	48.50	3.57
XX.	7	V.	English hay and soy bean hay,	579	28.468	94.89	11.36	10.29	32.30	43.20	2.85
XX.	7	VI.	English hay and soy bean hay,	619	28.790	95.05	10.96	9.25	34.41	42.70	2.68
XX.	8	IV.	English hay and carrots,	475	22.861	94.84	13.03	10.51	27.07	45.38	4.01
XX.	8	V.	English hay and carrots,	409	20.063	94.92	13.27	11.08	25.18	46.38	4.14
XX.	8	VI.	English hay and carrots,	440	20.806	94.40	14.89	10.50	25.90	44.58	4.13
XX.	9	IV.	English hay, gluten feed and carrots,	629	25.091	95.68	11.26	11.78	24.70	48.45	3.81
XX.	9	V.	English hay, gluten feed and carrots,	522	23.376	95.37	11.24	11.64	24.03	49.22	3.87
XX.	9	VI.	English hay, gluten feed and carrots,	509	21.084	95.33	12.23	11.53	24.30	47.79	4.15

TABLE II. — COMPOSITION OF FECES (PER CENT.) — *Continued.*

Series.	Period.	Sheep.	FEEDS.	Average Daily Feces (Grams).	One-tenth Feces Air-dry (Grams).	Dry Matter in Air-dry Feces.	DRY MATTER BASIS.				
							Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
XX.	10	VII.	English hay,	601	24.484	96.33	8.66	9.01	29.97	49.07	3.29
XX.	10	VIII.	English hay,	512	22.890	96.14	9.04	9.56	29.84	47.95	3.61
XX.	11	IV.	English hay, gluten feed and New Bedford pig meal,	582	29.587	95.22	15.16	14.44	25.00	42.98	2.42
XX.	11	V.	English hay, gluten feed and New Bedford pig meal,	692	26.733	95.13	16.34	15.79	22.78	42.55	2.54
XX.	11	VI.	English hay, gluten feed and New Bedford pig meal,	557	29.520	95.25	16.09	13.85	24.59	43.24	2.23
XX.	12	VII.	English hay and wheat gluten flour,	522	23.880	95.35	8.42	9.98	29.02	48.98	3.60
XX.	12	VIII.	English hay and wheat gluten flour,	596	23.559	95.33	8.82	10.67	27.96	49.03	3.52
XX.	13	IV.	English hay, gluten feed and vegetable ivory meal,	636	26.303	94.55	9.57	13.11	24.55	48.91	3.86
XX.	13	V.	English hay, gluten feed and vegetable ivory meal,	588	24.274	94.36	10.11	13.33	23.73	48.77	4.06
XX.	13	VI.	English hay, gluten feed and vegetable ivory meal,	555	23.789	94.18	10.81	12.91	23.67	48.28	4.33
XX.	14	IV.	English hay and gluten feed,	543	27.100	94.84	9.89	10.36	27.32	48.73	3.70
XX.	14	V.	English hay and gluten feed,	516	25.096	94.88	10.40	11.01	25.29	48.96	4.35
XX.	14	VI.	English hay and gluten feed,	503	24.679	95.14	10.11	10.95	25.70	49.27	3.97
XXI.	1	IV.	English hay and gluten feed,	491	23.619	92.98	11.96	10.86	26.32	46.84	4.02
XXI.	1	V.	English hay and gluten feed,	463	22.251	92.95	14.14	11.46	25.45	44.83	4.12
XXI.	1	VI.	English hay and gluten feed,	465	21.177	93.24	13.29	11.44	24.80	46.22	4.25
XXI.	2	VII.	English hay,	951	30.113	93.45	10.99	9.71	29.23	46.46	3.61

XXI.	2	VIII.	English hay, ...	729	25.607	93.30	11.25	10.83	26.74	47.09	4.09
XXI.	3	IV.	English hay, gluten feed and vegetable ivory meal, . .	612	25.816	94.13	10.06	13.32	25.25	47.43	3.94
XXI.	3	V.	English hay, gluten feed and vegetable ivory meal, . .	578	25.324	94.20	14.10	13.45	22.52	45.75	4.18
XXI.	3	VI.	English hay, gluten feed and vegetable ivory meal, . .	528	24.826	94.03	11.40	13.69	25.27	45.50	4.14
XXI.	4	VII.	English hay and wheat gluten flour, ...	737	29.360	94.85	9.41	9.28	30.42	47.29	3.60
XXI.	5	IV.	English hay, potato starch and gluten meal, ...	389	13.577	94.77	12.25	13.71	25.81	43.70	4.53
XXI.	5	V.	English hay, potato starch and gluten meal, ...	263	11.325	94.80	16.50	14.04	21.87	42.86	4.73
XXI.	5	VI.	English hay, potato starch and gluten meal, ...	292	13.214	94.80	13.53	13.69	24.88	43.48	4.42
XXI.	6	IV.	English hay, potato starch, gluten meal and distillers' grains,	502	19.628	94.91	9.61	15.11	24.29	46.41	4.58
XXI.	6	V.	English hay, potato starch, gluten meal and distillers' grains,	515	19.084	94.94	10.95	16.39	22.02	45.98	4.66
XXI.	6	VI.	English hay, potato starch, gluten meal and distillers' grains,	496	18.996	94.97	10.95	15.61	23.33	44.89	5.22
XXI.	7	IV.	English hay, potato starch, gluten meal and corn bran, .	483	16.470	95.61	9.36	14.32	23.02	49.02	4.28
XXI.	7	V.	English hay, potato starch, gluten meal and corn bran, .	532	15.782	95.59	9.89	18.64	19.51	47.54	4.42
XXI.	7	VI.	English hay, potato starch, gluten meal and corn bran, .	376	16.938	95.70	11.57	13.62	25.05	46.01	3.75
XXI.	8	IV.	English hay, gluten feed and New Bedford tankage, . .	596	28.648	95.01	13.18	15.79	24.83	43.10	3.10
XXI.	8	V.	English hay, gluten feed and New Bedford tankage, . .	542	24.460	94.76	13.99	18.80	20.73	43.19	3.29
XXI.	8	VI.	English hay, gluten feed and New Bedford tankage, . .	508	24.768	94.99	14.23	16.82	23.25	42.74	2.96
XXI.	9	IX.	English hay, ...	798	22.828	95.09	10.01	10.40	28.91	47.25	3.43
XXI.	9	X.	English hay, ...	620	24.422	95.29	9.15	9.13	30.15	47.95	3.62
XXI.	9	XI.	English hay, ...	689	25.755	95.22	9.43	9.74	30.50	46.81	3.52
XXI.	10	IV.	English hay and wheat gluten flour, ...	574	26.412	95.64	9.62	10.10	29.30	46.82	4.16
XXI.	10	VI.	English hay and wheat gluten flour, ...	670	28.847	95.64	9.99	10.20	27.97	47.72	4.12

TABLE II. — COMPOSITION OF FECES (PER CENT.) — *Concluded.*

Series.	Period.	Sheep.	FEEDS.	Average Daily Feces (Grams).	One-tenth Feces Air-dry (Grams).	Dry Matter in Air-dry Feces.	DRY MATTER BASIS.				
							Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
XXI.	11	V.	English hay and gluten feed,	414	19.858	94.61	14.97	14.13	22.69	43.85	4.36
XXI.	11	VI.	English hay and gluten feed,	416	19.337	94.92	16.77	14.05	21.58	43.31	4.29
XXI.	12	V.	English hay, gluten feed and feterita,	733	24.474	93.80	15.47	15.56	21.59	42.94	4.44
XXI.	12	VI.	English hay, gluten feed and feterita,	663	24.361	93.82	14.11	17.34	21.19	42.69	4.67
XXI.	13	XII.	English hay,	639	25.931	94.09	13.10	10.72	28.03	44.83	3.32
XXI.	13	XIII.	English hay,	698	26.630	94.02	13.34	10.58	29.04	43.52	3.52
XXI.	13	XIV.	English hay,	804	28.022	94.07	12.88	10.78	29.11	43.97	3.26
XXI.	14	IV.	English hay and sweet clover,	610	30.246	90.75	13.02	10.97	31.48	40.99	3.54
XXI.	14	VI.	English hay and sweet clover,	515	27.007	90.84	13.99	11.44	29.59	41.09	3.89
XXII.	1	IV.	English hay and Sudan grass,	711	31.687	93.03	13.47	12.19	24.69	46.04	3.61
XXII.	1	VI.	English hay and Sudan grass,	646	31.878	92.85	14.38	11.36	24.58	45.84	3.84
XXII.	2	IV.	English hay,	573	28.559	93.10	13.83	10.34	26.69	45.26	3.88
XXII.	2	VI.	English hay,	524	27.671	92.84	14.86	12.01	25.37	43.72	4.04
XXII.	3	IV.	English hay and Sudan grass,	683	30.929	93.90	13.40	13.28	23.28	46.80	3.24
XXII.	3	VI.	English hay and Sudan grass,	639	31.386	93.30	13.84	12.58	23.47	46.89	3.22
XXII.	4	IX.	English hay and Sudan grass,	739	27.021	95.49	8.18	10.68	28.77	50.40	1.97
XXII.	4	XI.	English hay and Sudan grass,	851	29.287	95.24	9.40	11.10	27.83	49.59	2.08
XXII.	6	IX.	Sudan grass,	828	26.671	94.32	10.55	13.53	25.80	47.42	2.70

XXII.	7	XI.	Sudan grass,	843	28.326	94.24	10.12	14.37	25.46	47.33	2.72
XXII.	7	XII.	Sudan grass,	673	25.321	94.52	10.39	14.82	24.54	47.04	3.21
XXII.	7	XIII.	Sudan grass,	761	25.447	94.61	10.12	14.22	25.71	47.06	2.89
XXII.	8	IV.	English hay,	622	29.557	94.43	10.46	10.57	27.82	47.80	3.35
XXII.	8	VI.	English hay,	579	28.237	94.45	10.69	10.82	27.23	47.81	3.45
XXII.	9	IX.	English hay and vinegar grains,	791	30.994	96.02	9.12	12.74	26.28	48.87	2.99
XXII.	9	XI.	English hay and vinegar grains,	1,332	31.883	93.17	9.80	13.34	25.77	48.29	2.80
XXII.	10	IV.	English hay and vinegar grains,	646	28.543	95.50	9.39	12.98	25.35	49.21	3.07
XXII.	10	VI.	English hay and vinegar grains,	619	28.157	95.28	10.80	13.79	23.51	48.63	3.27
XXII.	11	IV.	English hay and Stevens' "44" Dairy Ration,	643	26.957	95.39	10.46	12.09	26.71	47.64	3.10
XXII.	11	VI.	English hay and Stevens' "44" Dairy Ration,	719	27.779	95.82	11.62	12.81	24.74	47.44	3.39
XXII.	12	IV.	Alfalfa (third cutting, fine),	662	30.621	95.91	8.42	9.68	44.87	33.23	3.80
XXII.	12	VI.	Alfalfa (third cutting, fine),	1,113	30.053	95.40	9.60	10.66	42.81	33.34	3.59
XXII.	13	XII.	English hay,	671	26.875	95.33	9.19	9.46	30.63	47.33	3.39
XXII.	13	XIII.	English hay,	733	28.136	94.82	9.53	10.00	30.03	47.18	3.26
XXII.	14	XII.	Alfalfa (third cutting, fine),	847	26.907	95.87	8.58	10.63	44.44	32.79	3.56
XXII.	14	XIII.	Alfalfa (third cutting, fine),	871	27.750	95.51	8.26	10.01	45.80	32.57	3.36
XXII.	15	XII.	Rowen,	589	25.910	96.20	13.63	13.17	22.90	44.21	6.09
XXII.	15	XIII.	Rowen,	700	25.774	95.85	13.43	13.33	23.14	44.35	5.75
XXII.	16	IX.	Sweet clover and hay,	644	24.607	92.78	11.12	11.65	29.55	43.64	4.04
XXII.	16	XI.	Sweet clover and hay,	525	23.136	92.72	10.76	11.20	30.16	44.20	3.68
XXII.	17	XII.	English hay and Sudan grass,	649	23.501	91.80	7.54	11.21	27.13	50.59	3.53
XXII.	17	XIII.	English hay and Sudan grass,	580	25.304	93.18	11.38	10.34	27.95	46.71	3.62

TABLE III. — WEIGHT OF ANIMALS AT BEGINNING AND END OF EACH PERIOD, AND AVERAGE DAILY WATER CONSUMED.

Series.	Period.	Sheep.	FEEDS.	Average Water consumed (Cubic Centimeters).	BEGINNING (POUNDS).		END (POUNDS).	
					First Weight.	Second Weight.	First Weight.	Second Weight.
XVIII.	3	V.	English hay and mangels,	393	173.50	172.75	169.50	169.00
XVIII.	3	VI.	English hay and mangels,	1,012	161.50	161.50	158.50	158.50
XVIII.	4	I.	English hay and cabbage (heads),	384	140.75	140.75	134.75	134.75
XVIII.	4	II.	English hay and cabbage (heads),	999	135.50	136.00	133.50	134.50
XVIII.	5	I.	English hay and cabbage (leaves),	1,040	134.00	134.50	133.00	133.00
XVIII.	5	II.	English hay and cabbage (leaves),	1,530	134.00	134.00	132.00	132.50
XVIII.	6	V.	English hay and mangels,	371	173.25	171.50	160.75	159.25
XVIII.	6	VI.	English hay and mangels,	1,656	170.75	168.50	161.00	158.75
XVIII.	7	V.	English hay and turnips (Swedish),	363	167.25	166.25	157.65	155.75
XVIII.	7	VI.	English hay and turnips (Swedish),	1,544	165.50	165.75	156.00	156.00
XIX.	2	V.	English hay and gluten feed,	2,589	132.75	131.50	129.75	130.00
XIX.	2	VI.	English hay and gluten feed,	1,183	157.25	158.50	155.25	152.75
XIX.	3	I.	English hay,	2,367	144.00	143.50	141.25	140.50
XIX.	3	II.	English hay,	2,551	161.25	161.50	159.25	159.50
XIX.	4	I.	English hay and pumpkins (seed removed),	321	133.00	132.25	131.50	131.75
XIX.	4	II.	English hay and pumpkins (seed removed),	434	150.00	149.50	148.25	148.00
XIX.	5	V.	English hay, gluten feed and vegetable ivory meal,	2,049	140.50	138.00	137.25	137.25

XIX.	5	VI.	English hay, gluten feed and vegetable ivory meal,	1,156	161.00	159.25	163.50	165.50
XIX.	6	I.	English hay and pumpkins (entire),	469	136.00	135.75	135.00	135.50
XIX.	6	II.	English hay and pumpkins (entire),	704	149.75	148.75	149.25	149.50
XIX.	7	I.	English hay and cabbage (whole),	294	133.25	132.50	131.25	131.25
XIX.	7	II.	English hay and cabbage (whole),	1,489	148.50	147.75	146.75	145.75
XIX.	8	I.	English hay and carrots,	494	135.75	135.50	135.00	134.75
XIX.	8	II.	English hay and carrots,	1,653	147.00	147.25	148.25	147.50
XIX.	9	V.	English hay,	3,471	139.00	139.00	138.75	139.25
XIX.	9	VI.	English hay,	1,189	169.50	169.00	166.25	167.00
XIX.	10	III.	English hay, potato starch and gluten meal,	773	158.00	156.00	146.00	144.75
XIX.	10	IV.	English hay, potato starch and gluten meal,	3,080	186.50	184.50	180.75	179.75
XIX.	11	IV.	English hay, potato starch and gluten meal,	3,698	179.25	178.25	178.00	177.50
XIX.	12	IV.	English hay, potato starch, gluten meal and distillers' grains,	4,408	181.50	178.00	179.25	178.00
XIX.	13	I.	English hay and corn bran,	2,746	135.00	133.75	132.50	133.25
XIX.	13	II.	English hay and corn bran,	2,402	158.25	158.00	157.50	156.25
XIX.	14	V.	English hay and gluten feed,	2,416	132.50	131.50	136.00	137.00
XIX.	14	VI.	English hay and gluten feed,	1,559	162.50	161.75	160.75	163.75
XIX.	15	V.	English hay and gluten feed,	1,604	138.50	137.50	136.50	137.50
XIX.	15	VI.	English hay and gluten feed,	1,674	167.25	166.50	168.00	161.25
XX.	1	I.	English hay,	1,742	125.00	124.25	124.50	124.25
XX.	1	II.	English hay,	1,647	128.75	129.50	129.75	128.50
XX.	2	I.	English hay and pumpkins (entire),	115	120.25	120.25	120.25	120.50
XX.	2	II.	English hay and pumpkins (entire),	619	121.00	120.25	123.25	123.00

TABLE III. — WEIGHT OF ANIMALS AT BEGINNING AND END OF EACH PERIOD, AND AVERAGE DAILY WATER CONSUMED — *Continued.*

Series.	Period.	Sheep.	FEEDS.	Average Water consumed (Cubic Centimeters).	BEGINNING (POUNDS).		END (POUNDS).	
					First Weight.	Second Weight.	First Weight.	Second Weight.
XX.	3	I.	English hay, gluten feed and pumpkins (entire),	731	124.50	125.25	127.50	126.50
XX.	3	II.	English hay, gluten feed and pumpkins (entire),	815	126.00	127.25	128.25	128.00
XX.	4	I.	English hay, gluten feed and pumpkins (entire),	24	127.00	127.00	127.50	128.75
XX.	4	II.	English hay, gluten feed and pumpkins (entire),	123	132.25	132.25	132.25	131.25
XX.	5	I.	English hay and gluten feed,	1,533	124.25	124.50	125.75	126.50
XX.	5	II.	English hay and gluten feed,	1,584	130.25	129.75	127.50	128.75
XX.	6	IV.	English hay,	2,351	173.25	172.75	170.25	170.00
XX.	7	V.	English hay and soy bean hay,	1,049	147.75	148.75	141.00	143.00
XX.	7	VI.	English hay and soy bean hay,	1,353	152.50	151.25	152.00	152.00
XX.	8	IV.	English hay and carrots,	1,686	166.00	167.00	162.25	159.25
XX.	8	V.	English hay and carrots,	298	141.00	141.50	144.75	144.25
XX.	8	VI.	English hay and carrots,	923	149.75	152.00	148.50	147.75
XX.	9	IV.	English hay, gluten feed and carrots,	2,520	163.75	163.25	164.50	163.00
XX.	9	V.	English hay, gluten feed and carrots,	795	144.50	143.00	145.75	145.00
XX.	9	VI.	English hay, gluten feed and carrots,	1,461	148.25	148.25	149.75	149.75
XX.	10	VII.	English hay,	1,824	86.75	86.50	86.50	86.50
XX.	10	VIII.	English hay,	1,565	94.75	94.50	93.25	93.00

XX.	11	IV.	English hay, gluten feed and New Bedford pig meal,	3,650	170.25	169.50	167.00	166.50
XX.	11	V.	English hay, gluten feed and New Bedford pig meal,	1,546	146.75	147.25	147.25	147.75
XX.	11	VI.	English hay, gluten feed and New Bedford pig meal,	1,879	157.00	157.00	154.00	154.00
XX.	12	VII.	English hay and wheat gluten,	1,987	91.50	90.00	87.75	87.25
XX.	12	VIII.	English hay and wheat gluten,	1,956	97.25	96.25	96.50	96.25
XX.	13	IV.	English hay, gluten feed and vegetable ivory meal,	4,707	173.50	171.50	170.50	169.50
XX.	13	V.	English hay, gluten feed and vegetable ivory meal,	1,934	154.25	154.75	151.00	153.75
XX.	13	VI.	English hay, gluten feed and vegetable ivory meal,	2,193	157.00	157.00	156.00	156.25
XX.	14	IV.	English hay and gluten meal,	4,509	174.00	173.00	173.25	170.50
XX.	14	V.	English hay and gluten meal,	1,436	148.50	151.00	152.25	152.00
XX.	14	VI.	English hay and gluten meal,	2,207	157.25	156.50	155.75	155.50
XXI.	1	IV.	English hay and gluten feed,	3,497	156.75	158.50	158.00	157.75
XXI.	1	V.	English hay and gluten feed,	1,238	125.50	126.00	127.25	129.50
XXI.	1	VI.	English hay and gluten feed,	1,856	136.25	136.25	134.25	134.75
XXI.	2	VII.	English hay,	1,960	86.75	85.75	84.50	84.75
XXI.	2	VIII.	English hay,	1,621	93.50	94.00	94.50	94.25
XXI.	3	IV.	English hay, gluten feed and vegetable ivory meal,	2,641	159.00	160.00	159.00	158.50
XXI.	3	V.	English hay, gluten feed and vegetable ivory meal,	1,321	130.00	127.75	131.00	128.25
XXI.	3	VI.	English hay, gluten feed and vegetable ivory meal,	1,898	138.25	138.00	137.50	138.25
XXI.	4	VII.	English hay and wheat gluten flour,	1,743	84.25	84.25	83.00	82.50
XXI.	5	IV.	English hay, potato starch and gluten meal,	1,535	156.50	154.25	154.00	154.75
XXI.	5	V.	English hay, potato starch and gluten meal,	890	119.50	118.25	121.00	123.25
XXI.	5	VI.	English hay, potato starch and gluten meal,	852	130.25	131.50	126.00	126.50

TABLE III. — WEIGHT OF ANIMALS AT BEGINNING AND END OF EACH PERIOD, AND AVERAGE DAILY WATER CONSUMED — *Continued.*

Series.	Period.	Sheep.	FEEDS.	Average Water consumed (Cubic Centimeters).	BEGINNING (POUNDS).		END (POUNDS).	
					First Weight.	Second Weight.	First Weight.	Second Weight.
XXI.	6	IV.	English hay, potato starch, gluten meal and distillers' grains,	2,899	157.50	156.00	156.50	156.50
XXI.	6	V.	English hay, potato starch, gluten meal and distillers' grains,	951	124.50	122.25	126.50	124.00
XXI.	6	VI.	English hay, potato starch, gluten meal and distillers' grains,	2,091	128.00	127.25	128.00	126.00
XXI.	7	IV.	English hay, potato starch, gluten meal and corn bran,	3,296	157.00	155.25	157.00	156.25
XXI.	7	V.	English hay, potato starch, gluten meal and corn bran,	1,360	124.50	122.50	127.00	124.50
XXI.	7	VI.	English hay, potato starch, gluten meal and corn bran,	1,676	130.75	130.25	130.50	130.50
XXI.	8	IV.	English hay, gluten feed and New Bedford tankage,	3,924	161.25	160.50	158.50	159.25
XXI.	8	V.	English hay, gluten feed and New Bedford tankage,	1,978	128.50	129.75	133.50	133.00
XXI.	8	VI.	English hay, gluten feed and New Bedford tankage,	2,011	136.75	136.50	136.50	137.00
XXI.	9	IX.	English hay,	1,536	72.00	71.75	73.00	72.75
XXI.	9	X.	English hay,	1,178	70.50	69.75	66.25	70.25
XXI.	9	XI.	English hay,	1,209	76.00	79.25	79.00	79.25
XXI.	10	IV.	English hay and wheat gluten flour,	3,368	163.50	162.25	162.75	163.75
XXI.	10	VI.	English hay and wheat gluten flour,	2,146	140.50	140.25	139.25	140.25
XXI.	11	V.	English hay and gluten feed,	1,706	123.00	123.00	124.00	124.50
XXI.	11	VI.	English hay and gluten feed,	2,346	133.50	133.50	133.00	133.25
XXI.	12	V.	English hay, gluten feed and feterita,	2,195	123.50	124.00	126.00	126.00

XXI.	12	VI.	English hay, gluten feed and feterita,	2,153	135.50	136.75	137.75	137.00
XXI.	13	XII.	English hay,	2,824	98.50	95.50	94.75	95.00
XXI.	13	XIII.	English hay,	2,006	86.00	84.25	83.25	84.25
XXI.	13	XIV.	English hay,	1,825	86.50	85.75	83.75	84.25
XXI.	14	IV.	English hay and sweet clover,	1,708	150.50	149.00	146.00	146.00
XXI.	14	VI.	English hay and sweet clover,	986	126.50	126.00	127.00	127.25
XXII.	1	IV.	English hay and Sudan grass,	1,872	153.25	152.00	151.25	151.50
XXII.	1	VI.	English hay and Sudan grass,	842	138.25	135.00	132.25	132.75
XXII.	2	IV.	English hay,	2,889	149.50	148.00	146.50	147.00
XXII.	2	VI.	English hay,	1,663	132.00	130.25	131.50	130.50
XXII.	3	IV.	English hay and Sudan grass,	3,122	147.75	148.50	148.75	149.25
XXII.	3	VI.	English hay and Sudan grass,	1,740	133.75	131.75	129.00	129.00
XXII.	4	IX.	English hay and Sudan grass,	1,387	85.00	85.00	85.00	85.00
XXII.	4	XI.	English hay and Sudan grass,	1,362	95.75	95.25	94.75	93.50
XXII.	6	IX.	Sudan grass,	1,757	84.75	84.75	84.75	83.00
XXII.	7	XI.	Sudan grass,	1,938	91.00	88.25	88.50	87.75
XXII.	7	XII.	Sudan grass,	1,875	84.25	83.75	83.50	82.75
XXII.	7	XIII.	Sudan grass,	2,009	98.25	98.75	97.75	97.50
XXII.	8	IV.	English hay,	1,956	154.50	153.00	150.25	149.25
XXII.	8	VI.	English hay,	1,619	135.75	136.50	134.25	133.75
XXII.	9	IX.	English hay and vinegar grains,	1,804	90.00	89.50	91.25	91.25
XXII.	9	XI.	English hay and vinegar grains,	2,015	92.25	90.50	90.25	90.00
XXII.	10	IV.	English hay and vinegar grains,	3,250	147.75	147.25	146.25	146.75

TABLE III. — WEIGHT OF ANIMALS AT BEGINNING AND END OF EACH PERIOD, AND AVERAGE DAILY WATER CONSUMED — *Concluded.*

Series.	Period.	Sheep.	FEEDS.	Average Water consumed (Cubic Centimeters).	BEGINNING (POUNDS).		END (POUNDS).	
					First Weight.	Second Weight.	First Weight.	Second Weight.
XXII.	10	VI.	English hay and vinegar grains,	1,782	128.25	129.75	131.25	131.00
XXII.	11	IV.	English hay and Stevens' "44" Dairy Ration,	3,462	145.75	146.25	146.25	146.00
XXII.	11	VI.	English hay and Stevens' "44" Dairy Ration,	1,766	133.50	132.25	131.75	129.75
XXII.	12	IV.	Alfalfa (third cutting, fine),	3,685	146.75	147.00	145.00	143.50
XXII.	12	VI.	Alfalfa (third cutting, fine),	2,203	127.00	127.75	128.00	129.00
XXII.	13	XII.	English hay,	1,781	102.00	101.75	101.00	101.00
XXII.	13	XIII.	English hay,	2,068	88.50	87.75	87.50	87.50
XXII.	14	XII.	Alfalfa (third cutting, fine),	2,204	96.50	96.00	93.75	93.50
XXII.	14	XIII.	Alfalfa (third cutting, fine),	2,153	84.75	85.00	83.00	82.50
XXII.	15	XII.	Rowen,	2,041	97.00	96.25	98.00	97.50
XXII.	15	XIII.	Rowen,	1,875	84.75	85.25	85.75	86.00
XXII.	16	IX.	Sweet clover and hay,	1,083	97.00	96.75	99.75	101.75
XXII.	16	XI.	Sweet clover and hay,	784	97.50	96.50	100.50	101.75
XXII.	17	XII.	English hay and Sudan grass,	1,027	96.50	97.50	95.25	95.25
XXII.	17	XIII.	English hay and Sudan grass,	1,465	87.00	88.50	87.25	89.75

TABLE IV. — DIGESTION COEFFICIENTS OF BASAL RATIONS USED IN THE COMPUTATION OF DIGESTION COEFFICIENTS.

Series.	Period.	Sheep.	BASAL RATION.	Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.	SOURCE OF DATA.	
										Series.	Period.
XVIII.	4 and 5, . .	I. and II., . .	English hay, ...	65	31	61	70	67	53	XVIII.	I.[1]
XVIII.	3, 6 and 7, .	V. and VI., .	English hay, ...	65	46	65	67	67	46	XVII.	VIII.[2]
XIX.	2, 10 and 11, .	I., II., V. and VI.,	English hay, ...	59	28	52	62	62	47	XIX.	III. and IX.[3]
XIX.	10 and 11, .	– –	Corn starch, ...	100	–	–	–	100	–	–	–[4]
XIX.	4, 6, 7, 8 and 13,	I. and II., . .	English hay, ...	59	22	51	62	63	38	XIX.	III.
XIX.	12, ...	IV., ...	English hay, corn starch and gluten meal.	72	34	75	61	78	47	XIX.	XI.
XIX.	5, ...	V. and VI., .	English hay and gluten feed, . .	66	31	68	66	70	56	XIX.	II.
XIX.	14 and 15, .	V. and VI., .	English hay and gluten feed, . .	59	33	52	61	62	56	XIX.	IX.
XX.	2, ...	I. and II., . .	English hay, ...	64	38	51	69	66	48	XX.	I.
XX.	3 and 4, . .	I. and II., . .	English hay and gluten feed, . .	67	35	64	72	72	59	XX.	V.
XX.	7 and 8, . .	IV., V. and VI., .	English hay, ...	63	40	50	67	65	45	XX.	I and IV.[3]
XX.	9, 11 and 13, .	IV., V. and VI., .	English hay and gluten feed, . .	62	29	64	64	65	50	XX.	XIV.
XX.	12, ...	VII. and VIII., .	English hay, ...	59	47	41	63	62	47	XX.	X.
XXI.	1 and 5, . .	IV., V. and VI., .	English hay, ...	57	38	43	61	60	43	XXI.	II. and IX.[3]
XXI.	3 and 8, . .	IV., V. and VI., .	English hay and gluten feed, . .	67	29	69	68	71	48	XXI.	I.

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[1] See Bulletin No. 152, pp. 94, 99.

[2] See Bulletin No. 152, pp. 83, 93.

[3] Average coefficients of two experiments.

[4] Corn starch in all cases assumed to be entirely digested.

TABLE IV. — DIGESTION COEFFICIENTS OF BASAL RATIONS USED IN THE COMPUTATION OF DIGESTION COEFFICIENTS — *Concluded.*

Series.	Period.	Sheep.	BASAL RATION.	Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.	SOURCE OF DATA.	
										Series.	Period.
XXI.	4,	VII.,	English hay,	58	33	44	63	62	44	XXI.	II.
XXI.	5,	– –	Corn starch,	100	–	–	–	100	–	–	–[1]
XXI.	6 and 7,	IV., V. and VI.,	English hay, potato starch and gluten meal.	75	14	73	68	82	36	XXI.	V.
XXI.	11 and 14,	IV., V. and VI.,	English hay,	59	37	53	63	64	51	XXI.	XIII.
XXI.	12,	V. and VI.,	English hay and gluten feed,	71	38	71	75	75	50	XXI.	XI.
XXII.	1 and 3,	IV. and VI.,	English hay,	62	28	51	69	66	41	XXII.	II.
XXII.	9, 10 and 11,	IV. and VI.,	English hay,	61	41	51	68	63	45	XXII.	VIII.
XXII.	16,	IX. and XI.,	English hay,	58	45	48	63	60	45	XXIII.	I.[2]
XXII.	17,	XII. and XIII.,	English hay,	59	46	51	62	60	43	XXII.	XIII.

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[1] Corn starch in all cases assumed to be entirely digested.

[2] Unpublished to date.

TABLE V. — COMPUTATION OF DIGESTION COEFFICIENTS.

SERIES XVIII., MANGELS, PERIOD 3.

Sheep V.

ITEM.	Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
400 grams English hay fed,	347.00	19.67	34.25	109.51	174.24	9.33
1,400 grams mangels fed,	228.76	13.57	12.03	13.63	188.89	.64
Amount consumed,	575.76	33.24	46.28	123.14	363.13	9.97
Minus 159.94 grams feces excreted,	151.42	23.98	19.06	35.67	65.43	7.28
Amount digested,	424.34	9.26	27.22	87.47	297.70	2.69
Minus hay digested,	225.55	9.05	22.26	73.37	116.76	4.29
Mangels digested,	198.79	.21	4.96	14.10	180.94	-
Per cent. digested,	86.90	1.55	41.21	103.45	95.79	-

Sheep VI.

ITEM.	Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
Amount consumed as above,	575.76	33.24	46.26	123.14	363.13	9.97
Minus 155.50 grams feces excreted,	147.21	21.73	17.86	35.62	64.49	7.51
Amount digested,	428.55	11.51	28.42	87.52	298.64	2.46
Minus hay digested,	225.55	9.05	22.26	73.37	116.76	4.29
Mangels digested,	203.00	2.46	6.16	14.15	181.88	-
Per cent. digested,	88.74	18.12	51.18	103.81	96.29	-
Average per cent. digested,	87.82	9.84	46.20	103.73	96.04	-

SERIES XVIII., CABBAGE (HEADS), PERIOD 4.

Sheep I.

ITEM.	Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
400 grams English hay fed,	357.40	18.80	33.06	111.97	184.06	9.51
1,600 grams cabbage (heads) fed,	154.56	12.70	27.79	15.21	97.02	1.84
Amount consumed,	511.96	31.50	60.85	127.18	281.08	11.35
Minus 131.90 grams feces excreted,	125.34	15.44	17.08	29.82	57.67	5.33
Amount digested,	386.62	16.06	43.77	97.36	223.41	6.02
Minus hay digested,	232.31	5.83	20.17	78.38	123.32	5.04
Cabbage digested,	154.31	10.23	23.60	18.98	100.09	.98
Per cent. digested,	99.84	80.55	84.92	124.79	103.16	53.26

TABLE V. — COMPUTATION OF DIGESTION COEFFICIENTS — *Continued.*

SERIES XVIII., CABBAGE (HEADS), PERIOD 4 — *Concluded.*

Sheep II.

ITEM.	Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
Amount consumed as above,	511.96	31.50	60.85	127.18	281.08	11.35
Minus 138.19 grams feces excreted,	131.56	16.27	16.64	33.63	59.30	5.72
Amount digested,	380.40	15.23	44.21	93.55	221.78	5.63
Minus hay digested,	232.31	5.83	20.17	78.38	123.32	5.04
Cabbage digested,	148.09	9.40	24.04	15.17	98.46	.59
Per cent. digested,	95.81	74.02	86.51	99.74	101.48	32.07
Average per cent. digested,	97.83	77.29	85.72	112.32	102.32	42.67

SERIES XVIII., CABBAGE (LEAVES), PERIOD 5.

Sheep I.

400 grams English hay fed,	355.20	20.32	33.64	111.82	179.08	10.34
1,200 grams cabbage (leaves) fed,	228.60	33.12	27.29	29.99	132.69	5.51
Amount consumed,	583.80	53.44	60.93	141.81	311.77	15.85
Minus 186.23 grams feces excreted,	177.27	32.00	22.21	39.35	75.84	7.87
Amount digested,	406.53	21.44	38.72	102.46	235.93	7.98
Minus hay digested,	230.88	6.30	20.52	78.27	119.98	5.48
Cabbage digested,	175.65	15.14	18.20	24.19	115.95	2.50
Per cent. digested,	76.84	45.71	66.69	80.66	87.38	45.37

Sheep II.

Amount consumed as above,	583.80	53.44	60.93	141.81	311.77	15.85
Minus 199.50 grams feces excreted,	189.72	32.46	23.79	40.81	83.91	8.75
Amount digested,	394.08	20.98	37.14	101.00	227.86	7.10
Minus hay digested,	230.88	6.30	20.52	78.27	119.98	5.48
Cabbage digested,	163.20	14.68	16.62	22.73	107.88	1.62
Per cent. digested,	71.39	44.23	60.90	75.79	81.30	29.40
Average per cent. digested,	74.12	44.97	63.80	78.23	84.34	37.39

TABLE V. — COMPUTATION OF DIGESTION COEFFICIENTS — *Continued.*

SERIES XVIII., MANGELS, PERIOD 6.

Sheep V.

ITEM.	Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
400 grams English hay fed,	355.68	23.23	33.40	115.06	174.67	9.32
1,800 grams mangels fed,	312.84	19.65	20.08	21.30	251.00	.81
Amount consumed,	668.52	42.88	53.48	136.36	425.67	10.13
Minus 179.45 grams feces excreted,	170.08	24.07	22.06	40.19	74.20	9.56
Amount digested,	498.44	18.81	31.42	96.17	351.47	.57
Minus hay digested,	231.19	10.69	21.71	77.09	117.03	4.29
Mangels digested,	267.25	8.12	9.71	19.08	234.44	–
Per cent. digested,	85.43	41.31	48.36	89.58	93.40	–

Sheep VI.

ITEM.	Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
Amount consumed as above,	668.52	42.88	53.48	136.36	425.67	10.13
Minus 173.44 grams feces excreted,	164.54	21.90	19.12	41.10	73.52	8.90
Amount consumed,	503.98	20.98	34.36	95.26	352.15	1.23
Minus hay digested,	231.19	10.69	21.71	77.09	117.03	4.29
Mangels digested,	272.79	10.29	12.65	18.17	235.12	–
Per cent. digested,	87.20	52.36	63.00	85.31	93.67	–
Average per cent. digested,	81.32	46.84	55.68	87.45	93.58	–

SERIES XVIII., TURNIPS (SWEDISH), PERIOD 7.

Sheep V.

ITEM.	Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
400 grams English hay fed,	356.28	23.12	33.21	111.41	179.03	9.51
1,600 grams turnips fed,	220.64	16.17	21.14	24.25	157.34	1.74
Amount consumed,	576.92	39.29	54.35	135.66	336.37	11.25
Minus 156.48 grams feces excreted,	149.45	19.70	17.93	39.74	66.19	5.89
Amount digested,	427.47	19.59	36.42	95.92	270.18	5.36
Minus hay digested,	231.58	10.64	21.59	74.64	119.95	4.37
Turnips digested,	195.89	8.95	14.83	21.28	150.23	.99
Per cent. digested,	88.78	55.34	70.15	87.75	95.48	56.90

TABLE V. — COMPUTATION OF DIGESTION COEFFICIENTS — *Continued.*

SERIES XVIII., TURNIPS (SWEDISH), PERIOD 7 — *Concluded.*

Sheep VI.

ITEM.	Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
Amount consumed as above,	576.92	39.29	54.35	135.66	336.37	11.25
Minus 155.75 grams feces excreted,	148.59	20.34	15.62	42.70	64.37	5.56
Amount digested,	428.33	18.95	38.73	92.96	272.00	5.69
Minus hay digested,	231.58	10.64	21.59	74.64	119.95	4.37
Turnips digested,	196.75	8.31	17.14	18.32	152.05	1.32
Per cent. digested,	89.17	51.38	81.08	75.55	96.64	75.86
Average per cent. digested,	88.98	53.36	75.62	81.65	96.06	66.38

SERIES XIX., ENGLISH HAY AND GLUTEN FEED, — GLUTEN FEED, PERIOD 2.

Sheep V.

550 grams English hay fed,	484.11	28.22	46.09	152.01	246.80	10.99
150 grams gluten feed fed,	134.33	1.41	37.40	11.75	77.62	6.15
Amount consumed,	618.44	29.63	83.49	163.76	324.42	17.14
Minus 226.53 grams feces excreted,	209.47	19.38	26.79	57.86	97.92	7.52
Amount digested,	408.97	10.25	56.70	105.90	226.50	9.62
Minus hay digested,	285.62	7.90	23.97	94.25	153.02	5.16
Gluten feed digested,	123.35	2.35	32.73	11.65	73.48	4.46
Per cent. ration digested,	66.13	34.59	67.91	64.67	69.82	56.13
Per cent. gluten feed digested,	91.80	167.00	87.50	99.00	94.70	72.50

Sheep VI.

Amount consumed as above,	618.44	29.63	83.49	163.76	324.42	17.14
Minus 223 grams feces excreted,	206.48	21.62	26.06	54.70	96.65	7.45
Amount digested,	411.96	8.01	57.43	109.06	227.77	9.69
Minus hay digested,	285.62	7.90	23.97	94.25	153.02	5.16
Gluten feed digested,	126.34	.11	33.46	14.81	74.75	4.53
Per cent. ration digested,	66.61	27.03	68.79	66.60	70.21	56.53
Per cent. gluten feed digested,	94.70	.78	89.50	126.00	96.30	73.60
Average per cent. gluten feed digested,	93.25	83.89	88.50	112.50	95.50	73.05
Average per cent. ration digested,	66.37	30.81	68.35	65.64	70.02	56.33

TABLE V. — COMPUTATION OF DIGESTION COEFFICIENTS — *Continued.*

SERIES XIX., ENGLISH HAY, PERIOD 3.

Sheep I.

ITEM.	Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
800 grams English hay fed,	696.00	40.79	65.77	215.34	358.51	15.59
Minus 296.19 grams feces excreted,	279.99	32.39	33.49	75.71	128.80	9.60
English hay digested,	416.01	8.40	32.28	139.63	229.71	5.99
Per cent. digested,	59.77	20.59	49.08	64.84	64.07	38.42

Sheep II.

800 grams English hay fed,	696.00	40.79	65.77	215.34	358.51	15.59
Minus 315.10 grams feces excreted,	294.78	31.04	30.83	88.43	134.84	9.64
English hay digested,	401.22	9.75	34.94	126.91	223.67	5.95
Per cent. digested,	57.65	23.90	53.12	58.93	62.39	38.17
Average per cent. digested,	58.71	22.25	51.10	61.89	63.23	38.30

SERIES XIX., PUMPKINS (SEEDS REMOVED), PERIOD 4.

Sheep I.

500 grams English hay fed,	437.35	25.85	41.20	137.68	222.04	10.58
2,000 grams pumpkins fed,	108.40	9.55	14.89	18.79	62.39	2.78
Amount consumed,	545.75	35.40	56.09	156.47	284.43	13.36
Minus 180.47 grams feces excreted,	169.30	19.67	21.30	45.27	76.54	6.52
Amount digested,	376.45	15.73	34.79	111.20	207.89	6.84
Minus hay digested,	258.04	5.69	21.01	85.36	139.89	4.02
Pumpkins digested,	118.41	10.04	13.78	25.84	68.00	2.82
Per cent. digested,	109.23	105.13	92.55	137.52	108.99	101.44

Sheep II.

Amount consumed as above,	545.75	35.40	56.09	156.47	284.43	13.36
Minus 198.05 grams feces excreted,	185.99	24.03	21.09	53.23	80.63	7.01
Amount digested,	359.76	11.37	35.00	103.24	203.80	6.35
Minus hay digested,	258.04	5.69	21.01	85.36	139.89	4.02
Pumpkins digested,	101.72	5.68	13.99	17.88	63.91	2.33
Per cent. digested,	93.84	59.48	93.96	95.16	102.44	83.81
Average per cent. digested,	101.54	82.31	93.26	116.34	105.72	92.63

TABLE V. — COMPUTATION OF DIGESTION COEFFICIENTS — *Continued.*

SERIES XIX., VEGETABLE IVORY MEAL, PERIOD 5.

Sheep V.

ITEM.	Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
550 grams English hay fed,	484.28	28.14	45.67	153.52	245.91	11.04
150 grams gluten feed fed,	134.90	1.50	36.37	11.74	79.97	5.32
200 grams vegetable ivory meal fed,	174.72	2.39	10.52	12.27	148.33	1.21
Amount consumed,	793.90	32.03	92.56	177.53	474.21	17.57
Minus 252.10 grams feces excreted,	237.73	21.78	37.09	61.71	107.74	9.41
Amount digested,	556.17	10.25	55.47	115.82	366.47	8.16
Minus English hay and gluten feed digested,	408.66	9.19	55.79	109.07	228.12	9.16
Vegetable ivory meal digested,	147.51	1.06	–	6.75	138.35	–
Per cent. digested,	84.43	44.35	–	55.01	93.27	–

Sheep VI.

ITEM.	Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
Amount consumed as above,	793.90	32.03	92.56	177.53	474.21	17.57
Minus 241.94 grams feces excreted,	228.63	22.41	33.61	57.93	106.82	7.86
Amount digested,	565.27	9.62	58.95	119.60	367.39	9.71
Minus English hay and gluten feed digested,	408.66	9.19	55.79	109.07	228.12	9.16
Vegetable ivory meal digested,	156.61	.43	3.16	10.53	139.27	.55
Per cent. digested,	89.63	17.99	30.04	85.82	93.89	45.45
Average per cent. digested,	87.03	31.17	30.04	70.42	93.58	45.45[1]

SERIES XIX., PUMPKINS (ENTIRE), PERIOD 6.

Sheep I.

ITEM.	Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
550 grams English hay fed,	483.29	26.82	43.50	151.46	248.51	13.00
2,000 grams pumpkins fed,	176.20	13.39	31.22	29.71	76.01	25.87
Amount consumed,	659.49	40.21	74.72	181.17	324.52	38.87
Minus 253.33 grams feces excreted,	240.66	25.63	30.52	69.51	105.98	9.02
Amount digested,	418.83	14.58	44.20	111.66	218.54	29.85
Minus hay digested,	285.14	5.90	22.19	93.91	156.56	4.94
Pumpkins digested,	133.69	8.68	22.01	17.75	61.98	24.91
Per cent. digested,	75.87	64.82	70.50	59.74	81.54	96.29

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[1] One sheep only.

TABLE V. — COMPUTATION OF DIGESTION COEFFICIENTS — *Continued.*

SERIES XIX., PUMPKINS (ENTIRE), PERIOD 6 — *Concluded.*

Sheep II.

ITEM.	Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
Amount consumed as above,	659.49	40.21	74.72	181.17	324.52	38.87
Minus 228.69 grams feces excreted,	216.96	25.75	27.34	61.62	93.38	8.87
Amount digested,	442.53	14.46	47.38	119.55	231.14	30.00
Minus hay digested,	285.14	5.90	22.19	93.91	156.56	4.94
Pumpkins digested,	157.39	8.56	25.19	25.64	74.58	25.06
Per cent. digested,	89.32	63.93	80.69	86.30	98.12	96.87
Average per cent. digested,	82.60	64.38	75.60	73.02	89.83	96.58

SERIES XIX., CABBAGE (WHOLE), PERIOD 7.

Sheep I.

ITEM.	Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
450 grams English hay fed,	398.57	22.16	32.48	126.86	207.42	9.65
1,600 grams cabbage fed,	187.68	22.90	40.95	19.33	100.90	3.60
Amount consumed,	586.25	45.06	73.43	146.19	308.32	13.25
Minus 192.77 grams feces excreted,	183.40	26.50	22.23	46.36	81.29	7.02
Amount digested,	402.85	18.56	51.20	99.83	227.03	6.23
Minus hay digested,	235.16	4.88	16.56	78.65	130.67	3.67
Cabbage digested,	167.69	13.68	34.64	21.18	96.36	2.56
Per cent. digested,	89.35	59.74	84.59	109.57	95.50	71.11

Sheep II.

ITEM.	Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
Amount consumed as above,	586.25	45.06	73.43	146.19	308.32	13.25
Minus 200.09 grams feces excreted,	189.95	27.77	20.97	53.53	80.56	7.12
Amount digested,	396.30	17.29	52.46	92.66	227.76	6.13
Minus hay digested,	233.98	4.88	16.56	78.65	130.67	3.67
Cabbage digested,	162.32	12.41	35.90	14.01	97.09	2.46
Per cent. digested,	86.49	54.19	87.67	72.48	96.22	68.33
Average per cent. digested,	87.92	56.97	86.13	91.03	95.86	69.72

TABLE V. — COMPUTATION OF DIGESTION COEFFICIENTS — *Continued.*

SERIES XIX., CARROTS, PERIOD 8.

Sheep I.

ITEM.	Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
500 grams English hay fed,	443.75	25.43	36.08	153.80	218.41	10.03
1,500 grams carrots fed,	188.10	16.10	15.05	15.52	139.27	2.16
Amount consumed,	631.85	41.53	51.13	169.32	357.68	12.19
Minus 211.46 grams feces excreted,	202.45	30.55	24.90	53.49	86.85	6.66
Amount digested,	449.40	10.98	26.23	115.83	270.83	5.53
Minus hay digested,	261.81	5.59	18.40	95.36	137.60	3.81
Carrots digested,	167.59	5.39	7.83	20.47	133.23	1.72
Per cent. digested,	89.10	33.48	52.03	131.89	95.66	79.63

Sheep II.

Amount consumed as above,	631.85	41.53	51.13	169.32	357.68	12.19
Minus 194.84 grams feces excreted,	186.79	28.47	21.01	49.97	80.93	6.41
Amount digested,	445.06	13.06	30.12	119.35	276.75	5.78
Minus hay digested,	261.81	5.59	18.40	95.36	137.60	3.81
Carrots digested,	183.25	7.47	11.72	23.99	139.15	1.97
Per cent. digested,	94.42	46.40	77.87	154.57	99.91	91.20
Average per cent. digested,	93.26	39.94	64.95	143.23	97.79	85.42

SERIES XIX., ENGLISH HAY, PERIOD 9.

Sheep V.

800 grams English hay fed,	710.00	40.75	60.49	221.66	363.53	23.57
Minus 294.67 grams feces excreted,	279.97	27.10	28.11	81.30	133.44	10.02
Hay digested,	430.03	13.65	32.38	140.36	230.09	13.55
Per cent. digested,	60.57	33.50	53.53	63.32	63.29	57.49

Sheep VI.

800 grams English hay fed,	710.00	40.75	60.49	221.66	363.53	23.57
Minus 317.10 grams feces excreted,	301.56	27.38	29.58	91.64	142.35	10.61
Hay digested,	408.44	13.37	30.91	130.02	221.18	12.96
Per cent. digested,	57.53	32.81	51.10	58.66	60.84	54.99
Average per cent. digested,	59.05	33.16	52.32	60.99	62.07	56.24

TABLE V. — COMPUTATION OF DIGESTION COEFFICIENTS — *Continued.*

SERIES XIX., ENGLISH HAY, POTATO STARCH AND GLUTEN MEAL (DIAMOND), — GLUTEN MEAL (DIAMOND), PERIOD 10.

Sheep III.

ITEM.	Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
300 grams English hay fed, ...	270.81	15.60	20.50	86.85	141.55	6.31
125 grams potato starch fed, . . .	113.23	–	–	–	113.23	–
100 grams gluten meal (Diamond) fed, .	94.40	.81	42.47	2.04	47.37	1.71
Amount consumed, ...	478.44	16.41	62.97	88.89	302.15	8.02
Minus 132.41 grams feces excreted, . .	127.01	10.88	16.70	35.89	58.27	5.27
Amount digested, ...	351.43	5.53	46.27	53.00	243.88	2.75
Minus hay and starch (100 per cent.) digested,	273.01	4.37	10.66	53.85	200.99	2.96
Gluten meal (Diamond) digested, . .	78.42	1.16	35.61	–	42.89	–
Per cent. ration digested, ...	73.45	33.70	73.48	59.62	80.71	34.29
Per cent. gluten meal (Diamond) digested, .	83.07	143.20	83.85	–	90.54	–

Sheep IV.

Amount consumed as above, ...	478.44	16.41	62.97	88.89	302.15	8.02
Minus 147.44 grams feces excreted, . .	141.26	14.24	18.25	39.64	63.73	5.40
Amount digested, ...	337.18	2.17	44.72	49.25	238.42	2.62
Minus hay and starch (100 per cent.) digested,	273.01	4.37	10.66	53.85	200.99	2.75
Gluten meal (Diamond) digested, . .	64.17	–	34.06	–	37.43	–
Per cent. ration digested, ...	70.47	13.22	71.02	55.41	78.91	32.67
Per cent. gluten meal (Diamond) digested, .	68.00	–	80.00	–	79.00	–
Average per cent. ration digested, . .	71.96	23.46	72.25	57.52	79.81	33.48
Average per cent. gluten meal (Diamond) digested.	75.54	71.60	81.93	–	84.77	–

TABLE V. — COMPUTATION OF DIGESTION COEFFICIENTS — *Continued.*

SERIES XIX., ENGLISH HAY, POTATO STARCH AND GLUTEN MEAL (DIAMOND), — GLUTEN MEAL (DIAMOND), PERIOD 11.

Sheep IV.

ITEM.	Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
400 grams English hay fed,	369.40	20.91	25.93	118.47	195.37	8.72
125 grams potato starch fed,	112.80	–	–	–	112.80	–
125 grams gluten meal (Diamond) fed,	117.25	1.34	52.52	2.16	58.86	2.37
Amount consumed,	599.45	22.25	78.45	120.63	367.03	11.09
Minus 174.32 grams feces excreted,	166.84	14.70	19.60	47.37	79.30	5.87
Amount digested,	432.61	7.55	58.85	73.26	287.73	5.22
Minus hay and starch (100 per cent.) digested,	330.75	5.85	13.48	73.45	233.93	4.10
Gluten meal (Diamond) digested,	101.86	1.70	45.37	–	53.80	1.12
Per cent. ration digested,	72.17	33.93	75.02	60.73	78.39	47.07
Per cent. gluten meal (Diamond) digested,	86.90	127.00	86.40	–	91.40	47.30

SERIES XIX., DISTILLERS' GRAINS (CORN), PERIOD 12.

Sheep IV.

400 grams English hay fed,	359.00	21.72	26.42	115.10	184.99	10.77
125 grams gluten meal fed,	117.51	1.57	52.87	2.36	58.44	2.27
125 grams potato starch fed,	113.49	–	–	–	113.49	–
200 grams distillers' grains fed,	187.72	3.44	55.28	23.69	86.73	18.58
Amount consumed,	777.72	26.73	134.57	141.15	443.65	31.62
Minus 240.66 grams feces excreted,	229.42	20.35	31.20	65.64	104.06	8.17
Amount digested,	548.30	6.38	103.37	75.51	339.59	23.45
Minus hay, potato starch and gluten meal digested.	424.80	7.92	59.44	71.65	278.40	6.13
Distillers' grains digested,	123.50	–	43.93	3.86	61.19	17.32
Per cent. digested,	65.79	–	79.47	16.29	70.55	93.22

TABLE V. — COMPUTATION OF DIGESTION COEFFICIENTS — *Continued.*

SERIES XIX., CORN BRAN, PERIOD 13.

Sheep I.

ITEM.	Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
400 grams English hay fed,	363.48	22.28	25.52	119.33	188.21	8.14
350 grams corn bran fed,	316.47	2.72	16.52	45.89	247.32	4.02
Amount consumed,	679.95	25.00	42.04	165.22	435.53	12.16
Minus 191.02 grams feces excreted,	180.42	14.38	20.82	45.39	93.77	6.06
Amount digested,	499.53	10.62	21.22	119.83	341.76	6.10
Minus hay digested,	214.45	4.90	13.02	73.98	118.57	3.09
Corn bran digested,	285.08	5.72	8.20	45.85	223.19	3.01
Per cent. digested,	90.08	210.29	49.64	99.91	90.24	74.88

Sheep II.

Amount consumed as above,	679.95	25.00	42.04	165.22	435.53	12.16
Minus 234.41 grams feces excreted,	221.52	16.59	24.72	60.54	112.43	7.24
Amount digested,	458.43	8.41	17.32	104.68	323.10	4.92
Minus hay digested,	214.45	4.90	13.02	73.98	118.57	3.09
Corn bran digested,	243.98	3.51	4.30	30.70	204.53	1.83
Per cent. digested,	77.09	129.04	26.03	66.90	82.70	45.52
Average per cent. digested,	83.59	169.67	37.84	83.41	86.47	60.20

SERIES XIX., GLUTEN FEED, PERIOD 14.

Sheep V.

650 grams English hay fed,	584.68	35.14	48.47	184.47	300.93	15.67
150 grams gluten feed fed,	135.78	1.29	37.92	12.65	77.21	6.71
Amount consumed,	720.46	36.43	86.39	197.12	378.14	22.38
Minus 237.30 grams feces excreted,	223.20	20.47	29.04	58.17	105.94	9.58
Amount digested,	497.26	15.96	57.35	138.95	272.20	12.80
Minus hay digested,	344.96	11.60	25.20	112.53	186.58	8.78
Gluten feed digested,	152.30	4.36	32.15	26.42	85.62	4.02
Per cent. digested,	112.09	337.98	84.78	208.85	110.89	59.91

TABLE V. — COMPUTATION OF DIGESTION COEFFICIENTS — *Continued.*

SERIES XIX., GLUTEN FEED, PERIOD 14 — *Concluded.*

Sheep VI.

ITEM.	Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
Amount consumed as above,	720.46	36.43	86.39	197.12	378.14	22.38
Minus 262.21 grams feces excreted,	247.05	21.49	27.18	69.87	118.50	10.01
Amount digested,	473.41	14.94	59.21	127.25	259.64	12.37
Minus hay digested,	344.96	11.60	25.20	112.53	186.58	8.78
Gluten feed digested,	128.45	3.34	34.01	14.72	73.06	3.59
Per cent. digested,	94.54	258.91	89.69	116.36	94.63	53.50
Average per cent. digested,	103.32	298.45	87.24	162.61	102.76	56.71

SERIES XIX., ENGLISH HAY AND GLUTEN FEED, — GLUTEN FEED, PERIOD 15.

Sheep V.

650 grams English hay fed,	587.73	33.62	44.26	185.02	311.90	12.93
125 grams gluten feed fed,	113.59	2.61	29.35	9.28	66.97	5.38
Amount consumed,	701.32	36.23	73.61	194.30	378.87	18.31
Minus 246.94 grams feces excreted,	233.51	20.88	26.34	65.36	112.55	8.38
Amount digested,	467.81	15.35	47.27	128.94	266.32	9.93
Minus hay digested,	346.76	11.09	23.02	112.86	193.38	7.24
Gluten feed digested,	121.05	4.26	24.25	16.08	72.94	2.69
Per cent. ration digested,	66.70	42.45	64.22	66.36	70.29	54.23
Per cent. gluten feed digested,	106.57	163.22	82.62	173.28	108.91	50.00

Sheep VI.

Amount consumed as above,	701.32	36.23	73.61	194.30	378.87	18.31
Minus 280.06 grams feces excreted,	264.94	21.75	29.67	77.04	127.00	9.48
Amount digested,	436.38	14.48	43.94	117.26	251.87	8.83
Minus hay digested,	346.76	11.09	23.02	112.86	193.38	7.24
Gluten feed digested,	89.62	3.39	20.92	4.40	58.49	1.59
Per cent. ration digested,	62.22	39.97	59.69	60.35	66.48	48.23
Per cent. gluten feed digested,	78.90	129.89	71.28	47.41	87.34	29.55
Average per cent. ration digested,	64.46	41.21	61.96	63.36	68.39	51.23
Average per cent. gluten feed digested,	92.74	146.56	76.95	110.35	98.13	39.78

TABLE V. — COMPUTATION OF DIGESTION COEFFICIENTS — *Continued.*

SERIES XX., ENGLISH HAY, PERIOD 1.

Sheep I.

ITEM.	Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
800 grams English hay fed,	737.36	44.32	53.24	239.13	381.94	18.73
Minus 281.27 grams feces excreted,	260.32	26.73	26.16	70.75	126.89	9.79
English hay digested,	477.04	17.59	27.08	168.38	255.05	8.94
Per cent. digested,	64.70	39.69	50.86	70.41	66.78	48.67

Sheep II.

800 grams English hay fed,	737.36	44.32	53.24	239.13	381.94	18.73
Minus 291.37 grams feces excreted,	269.63	27.93	26.42	75.74	129.62	9.92
English hay digested,	467.73	16.39	26.82	163.39	252.32	8.81
Per cent. digested,	63.43	36.98	50.38	68.33	66.06	47.96
Average per cent. digested,	64.07	38.34	50.62	69.62	66.42	48.32

SERIES XX., PUMPKINS (ENTIRE), PERIOD 2.

Sheep I.

500 grams English hay fed,	449.50	27.96	30.66	145.10	231.62	14.16
2,000 grams pumpkins fed,	268.40	20.94	38.03	34.92	145.63	28.88
Amount consumed,	717.90	48.90	68.69	180.02	377.25	43.04
Minus 223.14 grams feces excreted,	211.14	23.42	27.03	57.13	93.09	10.47
Amount digested,	506.76	25.48	41.66	122.89	284.16	32.57
Minus hay digested,	287.68	10.62	15.84	100.12	152.87	6.79
Pumpkins digested,	219.08	14.86	25.82	22.77	131.29	25.78
Per cent. digested,	81.62	70.96	67.89	65.20	90.84	89.27

Sheep II.

Amount consumed as above,	717.90	48.90	68.69	180.02	377.25	43.04
Minus 203.70 grams feces excreted,	193.41	25.09	23.87	50.71	83.99	9.75
Amount digested,	524.49	23.81	44.82	129.31	293.26	33.29
Minus hay digested,	287.68	10.62	15.84	100.12	152.87	6.79
Pumpkins digested,	236.81	13.19	28.98	29.19	140.39	26.50
Per cent. digested,	88.23	62.99	76.20	83.59	96.40	91.76
Average per cent. digested,	84.93	66.98	72.05	74.39	93.62	90.52

TABLE V. — COMPUTATION OF DIGESTION COEFFICIENTS — *Continued.*

SERIES XX., PUMPKINS (ENTIRE), PERIOD 3.

Sheep I.

ITEM.	Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
550 grams English hay fed,	495.00	30.15	36.23	159.09	256.96	12.57
150 grams gluten feed fed,	136.65	2.51	34.91	11.30	81.58	6.35
1,200 grams pumpkins fed,	191.04	13.87	29.94	27.49	98.90	20.84
Amount consumed,	822.69	46.53	101.08	197.88	437.44	39.76
Minus 248.90 grams feces excreted,	236.31	25.62	30.51	62.06	108.34	9.78
Amount digested,	586.38	20.91	70.57	135.82	329.10	29.98
Minus hay and gluten feed digested,	435.84	11.43	45.53	122.68	243.75	11.62
Pumpkins digested,	150.54	9.48	25.04	13.14	85.35	18.36
Per cent. digested,	78.80	68.35	83.63	47.80	86.30	88.10

Sheep II.

Amount consumed as above,	822.69	46.53	101.08	197.88	437.44	39.76
Minus 255.64 grams feces excreted,	242.78	28.19	30.83	62.49	110.78	10.49
Amount digested,	579.91	18.34	70.25	135.39	326.66	29.27
Minus hay and gluten feed digested,	435.84	11.43	45.53	122.68	243.75	11.62
Pumpkins digested,	144.07	6.91	24.72	12.71	82.91	17.65
Per cent. digested,	75.41	49.82	82.57	46.23	83.83	84.69
Average per cent. digested,	77.11	59.09	83.10	47.02	85.07	86.40

SERIES XX., PUMPKINS (ENTIRE), PERIOD 4.

Sheep I.

412 grams English hay fed,	373.07	22.72	27.42	120.99	190.86	11.08
112 grams gluten feed fed,	102.73	2.09	26.56	8.49	60.82	4.77
2,000 grams pumpkins fed,	234.40	19.48	34.81	36.87	113.24	30.00
Amount consumed,	710.20	44.29	88.79	166.35	364.92	45.85
Minus 216.87 grams feces excreted,	204.77	20.62	28.20	58.93	88.79	8.23
Amount digested,	505.43	23.67	60.59	107.42	276.13	37.62
Minus hay and gluten feed digested,	328.30	8.68	34.55	93.23	181.21	9.35
Pumpkins digested,	177.13	14.99	26.04	14.19	94.92	28.27
Per cent. digested,	75.57	76.95	74.81	38.49	83.82	94.23

TABLE V. — COMPUTATION OF DIGESTION COEFFICIENTS — *Continued.*

SERIES XX., ENGLISH HAY AND GLUTEN FEED, — GLUTEN FEED, PERIOD 5.

Sheep I.

ITEM.	Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
550 grams English hay fed,	497.86	29.92	43.21	159.22	251.62	13.89
150 grams gluten feed fed,	136.71	2.67	36.54	11.39	79.82	6.29
Amount consumed,	634.57	32.59	79.75	170.61	331.44	20.18
Minus 197.54 grams feces excreted,	188.22	19.20	26.76	44.16	90.14	7.96
Amount digested,	446.35	13.39	52.99	126.45	241.30	12.22
Minus hay digested,	318.63	11.37	22.04	109.86	166.07	6.71
Gluten feed digested,	127.72	2.02	30.95	16.59	75.23	5.51
Per cent. ration digested,	70.34	41.09	66.45	74.12	72.80	60.56
Per cent. gluten feed digested,	93.42	75.66	84.70	145.65	94.25	87.60

Sheep II.

ITEM.	Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
Amount consumed as above,	634.57	32.59	79.75	170.61	331.44	20.18
Minus 221.18 grams feces excreted,	211.36	23.19	30.77	51.87	97.12	8.41
Amount digested,	423.21	9.40	48.98	118.74	234.32	11.77
Minus hay digested,	318.63	11.37	22.04	109.86	166.07	6.71
Gluten feed digested,	104.58	–	26.94	8.88	68.25	5.06
Per cent. ration digested,	66.69	28.84	61.42	69.60	70.70	58.33
Per cent. gluten feed digested,	76.50	–	73.73	77.96	85.50	80.45
Average per cent. ration digested,	68.52	34.97	63.94	71.86	71.75	59.45
Average per cent. gluten feed digested,	84.96	75.66[1]	79.22	111.81	89.88	84.03

SERIES XX., ENGLISH HAY, PERIOD 6.

Sheep IV.

ITEM.	Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
800 grams English hay fed,	717.84	44.22	53.41	230.28	272.99	16.94
Minus 300.50 grams feces excreted,	288.33	25.63	27.59	84.97	139.85	10.29
Amount digested,	429.51	18.59	25.82	145.31	233.14	6.65
Per cent. digested,	60.08	42.04	48.34	63.10	62.51	39.26

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[1] One sheep only.

TABLE V. — COMPUTATION OF DIGESTION COEFFICIENTS — *Continued.*

SERIES XX., SOY BEAN HAY, PERIOD 7.

Sheep V.

ITEM.	Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
400 grams English hay fed,	367.68	22.39	26.95	120.19	189.51	8.64
Minus 29.03 grams waste,	27.24	1.64	1.74	9.57	13.86	.43
Amount consumed,	340.44	20.75	25.21	110.62	175.65	8.21
400 grams soy bean hay fed,	353.08	23.41	56.00	123.15	143.21	7.31
Minus 55.1 grams waste,	51.00	2.77	3.76	22.93	21.13	.41
Amount soy bean hay fed,	302.08	20.64	52.24	100.22	122.08	6.90
Amount consumed,	642.52	41.39	77.45	210.84	297.73	15.11
Minus 284.68 grams feces excreted,	270.13	30.69	27.80	87.25	116.69	7.70
Amount digested,	372.39	10.70	49.65	123.59	181.04	7.41
Minus hay digested,	214.48	8.30	12.61	74.12	114.17	3.69
Amount soy bean hay digested,	157.91	2.40	37.04	49.47	66.87	3.72
Per cent. digested,	52.27	11.63	70.90	49.36	54.78	53.91

Sheep VI.

ITEM.	Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
400 grams English hay fed,	367.68	22.39	26.95	120.19	189.51	8.64
400 grams soy bean hay fed,	353.08	23.41	56.00	123.15	143.21	7.31
Amount consumed,	720.76	45.80	82.95	243.34	332.72	15.95
Minus 287.90 grams feces excreted,	273.65	29.99	25.31	94.16	116.86	7.33
Amount digested,	447.11	15.81	57.64	149.18	215.86	8.62
Minus hay digested,	231.64	8.96	13.48	80.53	123.18	3.89
Soy bean hay digested,	215.47	6.85	44.16	68.65	92.68	4.73
Per cent. digested,	61.03	29.26	78.86	55.75	64.72	64.71
Average per cent. digested,	56.65	20.45	74.88	52.56	59.75	59.31

SERIES XX., CARROTS, PERIOD 8.

Sheep IV.

ITEM.	Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
500 grams English hay fed,	449.85	30.23	35.72	146.34	225.95	11.61
1,500 grams carrots fed,	196.95	20.31	22.12	17.39	135.12	2.01
Amount consumed,	646.80	50.54	57.84	163.73	361.07	13.62
Minus 228.61 grams feces excreted,	216.81	28.25	22.79	58.69	98.39	8.69
Amount digested,	429.99	22.29	35.05	105.04	262.68	4.93
Minus hay digested,	283.41	12.09	17.86	98.05	146.87	5.22
Carrots digested,	146.58	10.20	17.19	6.99	115.81	–
Per cent. digested,	74.42	50.22	77.71	40.19	85.71	–

TABLE V. — COMPUTATION OF DIGESTION COEFFICIENTS — *Continued.*

SERIES XX., CARROTS, PERIOD 8 — *Concluded.*

Sheep V.

ITEM.	Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
Amount consumed as above,	646.80	50.54	57.84	163.73	361.07	13.62
Minus 200.63 grams feces excreted,	190.44	25.27	21.10	47.95	88.24	7.88
Amount digested,	456.36	25.27	36.74	115.78	272.83	5.74
Minus hay digested,	283.41	12.09	17.86	98.05	146.87	5.22
Carrots digested,	172.95	13.18	18.88	17.73	125.96	.52
Per cent. digested,	87.81	64.89	85.35	101.96	93.22	25.87

Sheep VI.

ITEM.	Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
Amount consumed as above,	646.80	50.54	57.84	163.73	361.07	13.62
Minus 208.06 grams feces excreted,	198.49	29.56	20.84	51.41	88.48	8.20
Amount digested,	448.31	20.98	37.00	112.32	272.59	5.42
Minus hay digested,	283.41	12.09	17.86	98.05	146.87	5.22
Carrots digested,	164.90	8.89	19.14	14.27	125.72	.20
Per cent. digested,	83.73	43.77	86.53	82.06	93.04	9.95
Average per cent. digested,	81.99	52.96	83.20	74.74	90.66	17.91[1]

SERIES XX., CARROTS, PERIOD 9.

Sheep IV.

ITEM.	Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
550 grams English hay fed,	497.04	30.97	37.78	151.30	263.72	13.27
150 grams gluten feed fed,	137.03	3.04	36.41	10.63	80.36	6.59
1,000 grams carrots fed,	114.00	11.18	12.67	9.69	79.22	1.24
Amount consumed,	748.07	45.19	86.86	171.62	423.30	21.10
Minus 250.91 grams feces excreted,	240.07	27.03	28.28	59.30	116.31	9.15
Amount digested,	508.00	18.16	58.58	112.32	306.99	11.95
Minus hay and gluten feed digested,	393.12	9.86	47.48	103.64	223.65	9.93
Carrots digested,	114.88	8.30	11.10	8.68	83.34	2.02
Per cent. digested,	100.70	74.24	87.61	89.58	105.20	162.90

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[1] Two sheep only.

TABLE V. — COMPUTATION OF DIGESTION COEFFICIENTS — *Continued.*

SERIES XX., CARROTS, PERIOD 9 — *Concluded.*

Sheep V.

ITEM.	Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
Amount consumed as above,	748.07	45.19	86.86	171.62	423.30	21.10
Minus 233.76 grams feces excreted,	222.94	25.06	25.95	53.57	109.73	8.63
Amount digested,	525.13	20.13	60.91	118.05	313.57	12.47
Minus hay and gluten feed digested,	393.12	9.86	47.48	103.64	223.65	9.93
Carrots digested,	132.01	10.27	13.43	14.41	89.92	2.54
Per cent. digested,	115.80	91.86	106.00	148.71	113.51	204.84

Sheep VI.

Amount consumed as above,	748.07	45.19	86.86	171.62	423.30	21.10
Minus 210.84 grams feces excreted,	200.99	24.58	23.17	48.84	96.06	8.34
Amount digested,	547.08	20.61	63.69	122.78	327.24	12.76
Minus hay and gluten feed digested,	393.12	9.86	47.48	103.64	223.65	9.93
Carrots digested,	153.96	10.75	16.21	19.14	103.59	2.83
Per cent. digested,	135.05	96.15	127.94	197.52	130.76	228.23
Average per cent. digested,	113.85	87.42	107.18	145.27	116.49	198.66

SERIES XX., ENGLISH HAY, PERIOD 10.

Sheep VII.

600 grams English hay fed,	546.00	35.65	44.50	174.83	277.37	13.65
Minus 244.84 grams feces excreted,	235.85	20.42	21.25	70.68	115.74	7.76
Amount digested,	310.15	15.23	23.25	104.15	161.63	5.89
Per cent. digested,	56.80	42.72	52.25	59.57	58.27	43.15

Sheep VIII.

600 grams English hay fed,	546.00	35.65	44.50	174.83	277.37	13.65
Minus 228.90 grams feces excreted,	220.06	19.89	21.04	65.67	105.52	7.94
Amount digested,	325.94	15.76	23.46	109.16	171.85	5.71
Per cent. digested,	59.70	44.21	52.72	62.44	61.96	41.83
Average per cent. digested,	58.25	43.47	52.49	61.01	60.12	42.49

TABLE V. — COMPUTATION OF DIGESTION COEFFICIENTS — *Continued.*

SERIES XX., NEW BEDFORD PIG MEAL, PERIOD 11.

Sheep IV.

ITEM.	Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
550 grams English hay fed,	455.35	30.96	39.02	146.35	227.64	11.38
150 grams gluten feed fed,	137.18	2.96	34.94	11.48	81.46	6.34
200 grams New Bedford pig meal fed,	182.40	35.84	43.03	16.69	80.80	6.04
Amount consumed,	774.93	69.76	116.99	174.52	389.90	23.76
Minus 295.87 grams feces excreted,	281.73	42.71	40.68	70.43	121.09	6.82
Amount digested,	493.20	27.05	76.31	104.09	268.81	16.94
Minus hay and gluten feed digested,	367.37	9.84	47.33	101.01	200.92	8.86
New Bedford pig meal digested,	125.83	17.21	28.98	3.08	67.89	8.08
Per cent. digested,	68.99	48.02	67.35	18.45	84.02	133.77

Sheep VI.

Amount consumed as above,	774.93	69.76	116.99	174.52	389.90	23.76
Minus 295.20 grams feces excreted,	281.18	45.24	38.94	69.14	121.59	6.27
Amount digested,	493.75	24.52	78.05	105.38	268.31	17.49
Minus hay and gluten feed digested,	367.37	9.84	47.33	101.01	200.92	8.86
New Bedford pig meal digested,	126.38	14.68	30.72	4.37	67.39	8.63
Per cent. digested,	69.29	40.96	71.39	26.18	83.40	142.88
Average per cent. digested,	69.14	44.49	69.37	22.32	83.71	138.33

SERIES XX., ENGLISH HAY AND WHEAT GLUTEN FLOUR, PERIOD 12.[1]

Sheep VII.

600 grams English hay fed,	554.70	37.00	39.77	173.73	289.00	15.20
40 grams wheat gluten fed,	36.66	.32	33.88	.04	2.28	.14
Amount consumed,	591.36	37.32	73.65	173.77	291.28	15.34
Minus 238.80 grams feces excreted,	227.70	19.17	22.72	66.08	111.53	8.20
Amount digested,	363.66	18.15	50.93	107.69	179.75	7.14
Minus wheat gluten (assumed to be all digested).	36.66	.32	33.88	.04	2.28	.14
Hay digested,	327.00	17.83	17.05	107.65	177.47	7.00
Per cent. digested,	58.95	48.19	42.87	61.96	61.44	46.05

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[1] To note effect of wheat gluten flour.

TABLE V. — COMPUTATION OF DIGESTION COEFFICIENTS — *Continued.*

SERIES XX., ENGLISH HAY AND WHEAT GLUTEN FLOUR, PERIOD 12 — *Concluded.*

Sheep VIII.

ITEM.	Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
Amount consumed as above,	591.36	37.32	73.65	173.77	291.38	15.34
Minus 235.59 grams feces excreted,	224.59	19.81	23.96	62.80	110.11	7.91
Amount digested,	366.77	17.51	49.69	110.97	181.17	7.43
Minus wheat gluten (assumed to be all digested).	36.66	.32	33.88	.04	2.28	.14
Hay digested,	330.11	17.19	15.81	110.93	178.89	7.29
Per cent. digested,	59.51	46.46	39.75	63.85	61.90	47.96
Average per cent. digested,	59.23	47.33	41.31	62.91	61.99	47.01

SERIES XX., VEGETABLE IVORY MEAL, PERIOD 13.

Sheep IV.

500 grams English hay fed,	460.10	29.45	33.59	148.24	237.46	11.36
150 grams gluten feed fed,	137.70	2.96	35.58	11.31	81.72	6.13
200 grams vegetable ivory meal fed,	182.50	2.17	8.61	15.09	155.22	1.41
Amount consumed,	780.30	34.58	77.78	174.64	474.40	18.90
Minus 263.03 grams feces excreted,	248.69	23.80	32.60	61.05	121.64	9.60
Amount digested,	531.61	10.78	45.18	113.59	352.76	9.30
Minus hay and gluten feed digested,	370.64	9.40	44.27	102.11	207.47	8.75
Vegetable ivory meal digested,	160.97	1.38	.91	11.48	145.28	.55
Per cent. digested,	88.20	63.59	10.57	76.08	93.60	39.01

Sheep V.

Amount consumed as above,	780.30	34.58	77.78	174.64	474.40	18.90
Minus 242.74 grams feces excreted,	229.05	23.14	30.53	54.35	111.73	9.30
Amount digested,	551.25	11.44	47.25	120.29	362.67	9.60
Minus hay and gluten feed digested,	370.64	9.40	44.27	102.11	207.47	8.75
Vegetable ivory meal digested,	180.61	2.04	2.98	18.18	155.20	.85
Per cent. digested,	98.96	94.01	34.61	120.48	99.99	60.28

TABLE V. — COMPUTATION OF DIGESTION COEFFICIENTS — *Continued.*

SERIES XX., VEGETABLE IVORY MEAL, PERIOD 13 — *Concluded.*

Sheep VI.

ITEM.	Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
Amount consumed as above,	780.30	34.58	77.78	174.64	474.40	18.90
Minus 237.89 grams feces excreted,	224.04	24.22	28.92	53.03	108.17	9.70
Amount digested,	556.26	10.36	48.86	121.61	366.23	9.20
Minus hay and gluten feed digested,	370.64	9.40	44.27	102.11	207.47	8.75
Vegetable ivory meal digested,	185.62	.96	3.59	19.50	158.76	.45
Per cent. digested,	101.71	44.24	41.70	129.22	102.28	31.91
Average per cent. digested,	96.29	67.28	28.96	108.59	98.62	43.73

SERIES XX., ENGLISH HAY AND GLUTEN FEED, — GLUTEN FEED, PERIOD 14.

Sheep IV.

550 grams English hay fed,	509.41	31.94	35.40	165.25	263.63	13.19
150 grams gluten feed fed,	138.14	2.94	37.45	11.81	79.74	6.20
Amount consumed,	647.55	34.88	72.85	177.06	343.37	19.39
Minus 271 grams feces excreted,	257.02	25.42	26.63	70.22	125.24	9.51
Amount digested,	390.53	9.46	46.22	106.84	218.13	9.88
Minus hay digested,	320.93	12.78	17.70	110.72	171.36	5.94
Gluten feed digested,	69.60	–	28.52	–	46.77	3.94
Per cent. ration digested,	60.31	27.12	63.45	60.34	63.53	50.95
Per cent. gluten feed digested,	50.38	–	76.15	–	58.65	63.55

Sheep V.

Amount consumed as above,	647.55	34.88	72.85	177.06	343.37	19.39
Minus 250.96 grams feces excreted,	238.11	24.76	26.22	60.22	116.58	10.33
Amount digested,	409.44	10.12	46.63	116.84	226.79	9.06
Minus hay digested,	320.93	12.78	17.70	110.72	171.36	5.94
Gluten feed digested,	88.51	–	28.93	6.12	55.43	3.12
Per cent. ration digested,	63.23	29.01	64.01	65.99	66.05	46.73
Per cent. gluten feed digested,	64.07	–	77.25	51.82	69.51	50.32

TABLE V. — COMPUTATION OF DIGESTION COEFFICIENTS — *Continued.*

SERIES XX., ENGLISH HAY AND GLUTEN FEED, — GLUTEN FEED, — PERIOD 14 — *Concluded.*

Sheep VI.

ITEM.	Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
Amount consumed as above,	647.55	34.88	72.85	177.06	343.37	19.39
Minus 246.79 grams feces excreted,	234.80	23.74	25.71	60.34	115.69	9.32
Amount digested,	412.75	11.14	47.14	116.72	227.68	10.07
Minus hay digested,	320.93	12.78	17.70	110.72	171.36	5.94
Gluten feed digested,	91.82	–	29.44	6.00	56.32	4.13
Per cent. ration digested,	63.74	31.94	64.71	65.92	66.31	51.93
Per cent. gluten feed digested,	66.47	–	78.61	50.80	70.63	66.01
Average per cent. ration digested,	62.43	29.36	64.06	64.08	65.30	49.87
Average per cent. gluten feed digested,	60.31	–	77.34	51.31[1]	66.26	60.16

SERIES XXI., ENGLISH HAY AND GLUTEN FEED, — GLUTEN FEED, PERIOD 1.

Sheep IV.

ITEM.	Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
550 grams English hay fed,	491.43	33.96	37.10	157.55	248.91	13.91
150 grams gluten feed fed,	135.48	4.55	38.33	10.07	80.08	2.45
Amount consumed,	626.91	38.51	75.43	167.62	328.99	16.36
Minus 236.19 grams feces excreted,	219.61	26.27	23.85	57.80	102.86	8.83
Amount digested,	407.30	12.24	51.58	109.82	226.13	7.53
Minus hay digested,	280.12	12.90	15.95	96.11	149.35	5.98
Gluten feed digested,	127.18	–	35.63	13.71	76.78	1.55
Per cent. ration digested,	64.97	31.78	68.38	65.52	68.73	46.03
Per cent. gluten feed digested,	93.87	–	92.96	136.00	95.88	63.27

Sheep V.

ITEM.	Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
550 grams minus 1.86 grams waste equals 548.14 grams English hay fed.	489.76	33.84	36.98	157.02	248.06	13.86
150 grams gluten feed fed,	135.48	4.55	38.33	10.07	80.08	2.45
Amount consumed,	625.24	38.39	75.31	167.09	328.14	16.31
Minus 222.51 grams feces excreted,	206.82	29.24	23.70	52.64	92.72	8.52
Amount digested,	418.42	9.15	51.61	114.45	235.42	7.79
Minus hay digested,	279.16	12.86	15.90	95.78	148.84	5.96
Gluten feed digested,	139.26	–	35.71	18.67	86.58	1.83
Per cent. ration digested,	66.92	23.83	68.53	68.50	71.74	47.76
Per cent. gluten feed digested,	102.79	–	93.16	185.00	108.12	74.69

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[1] Two sheep only.

TABLE V. — COMPUTATION OF DIGESTION COEFFICIENTS — *Continued.*

SERIES XXI., ENGLISH HAY AND GLUTEN FEED, — GLUTEN FEED, — PERIOD 1 — *Concluded.*

Sheep VI.

ITEM.	Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
Amount consumed as for Sheep IV., . .	626.91	38.51	75.43	167.62	328.99	16.36
Minus 211.77 grams feces excreted, . .	195.55	25.99	22.37	48.50	90.38	8.31
Amount digested, ...	431.36	12.52	53.06	119.12	238.61	8.05
Minus hay digested, ...	280.12	12.90	15.95	96.11	149.35	5.98
Gluten feed digested, ...	151.24	–	37.11	23.01	89.26	2.07
Per cent. ration digested, ...	68.81	32.51	70.34	71.07	72.53	49.21
Per cent. gluten feed digested, . . .	111.63	–	96.82	228.00	111.46	84.49
Average per cent. ration digested, . .	66.90	29.37	69.08	68.36	71.00	47.67
Average per cent. gluten feed digested, .	102.76	–	94.31	183.00	105.15	74.15

SERIES XXI., ENGLISH HAY, PERIOD 2.

Sheep VII.

700 grams English hay fed, ...	623.84	43.11	47.10	200.01	315.97	17.65
Minus 301.12 grams feces excreted, . .	281.40	30.93	27.32	82.25	130.74	10.16
Amount digested, ...	342.44	12.18	19.78	117.76	185.23	7.49
Per cent. digested, ...	54.89	28.25	42.00	58.88	58.62	42.44

Sheep VIII.

700 grams English hay fed, ...	623.84	43.11	47.10	200.01	315.97	17.65
Minus 256.07 grams feces excreted, . .	238.91	26.88	25.87	63.88	112.51	9.77
Amount digested, ...	384.93	16.23	21.33	136.13	203.46	7.88
Per cent. digested, ...	61.70	37.65	45.08	68.06	64.39	44.65
Average per cent. digested, . . .	58.30	32.95	43.54	63.47	61.51	43.55

Table V. — Computation of Digestion Coefficients — *Continued.*

Series XXI., Vegetable Ivory Meal, Period 3.

Sheep IV.

Item.	Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
550 grams English hay fed,	486.20	32.48	36.51	158.21	245.05	13.95
150 grams gluten feed fed,	135.66	4.73	38.05	9.90	80.55	2.43
200 grams minus 1.86 grams waste equals 198.14 grams vegetable ivory meal fed.	176.54	2.10	9.41	15.45	146.83	2.75
Amount consumed,	798.40	39.31	83.97	183.56	472.43	19.13
Minus 258.16 grams feces excreted,	243.01	24.45	32.37	61.36	115.26	9.57
Amount digested,	555.39	14.86	51.60	122.20	357.17	9.56
Minus hay and gluten feed digested,	416.65	10.79	51.45	114.31	231.18	7.86
Vegetable ivory meal digested,	138.74	4.07	.15	7.89	125.99	1.70
Per cent. digested,	78.59	193.81	1.59	51.07	85.81	61.82

Sheep V.

Item.	Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
550 grams minus .7 gram waste equals 549.3 grams English hay fed.	485.58	32.44	36.47	158.01	244.72	13.94
150 grams gluten feed fed,	135.66	4.73	38.05	9.90	80.55	2.43
200 grams minus 1.43 grams waste equals 198.57 grams vegetable ivory meal fed.	176.93	2.11	9.43	15.48	147.15	2.76
Amount consumed,	798.17	39.28	83.95	183.39	472.42	19.13
Minus 253.24 grams feces excreted,	238.55	33.64	32.08	53.72	109.14	9.97
Amount digested,	559.62	5.64	51.87	129.67	363.28	9.16
Minus hay and gluten feed digested,	416.23	10.78	51.42	114.18	230.94	7.86
Vegetable ivory meal digested,	143.39	–	.45	15.49	132.34	1.30
Per cent. digested,	81.04	–	4.77	100.06	89.94	47.10

Sheep VI.

Item.	Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
550 grams English hay fed,	486.20	32.48	36.51	158.21	245.05	13.95
150 grams gluten feed fed,	135.66	4.73	38.05	9.90	80.55	2.43
200 grams minus 1.57 grams equals 198.43 grams vegetable ivory meal fed.	176.81	2.10	9.42	15.47	147.06	2.76
Amount consumed,	798.67	39.31	83.98	183.58	472.66	19.14
Minus 248.26 grams feces excreted,	233.44	26.61	31.96	58.99	106.22	9.66
Amount digested,	565.23	12.70	52.02	124.59	366.44	9.48
Minus hay and gluten feed digested,	416.65	10.79	51.45	114.31	231.18	7.86
Vegetable ivory meal digested,	148.58	1.91	.57	10.28	135.26	1.62
Per cent. digested,	84.03	90.95	6.04	66.45	91.98	58.70
Average per cent. digested,	81.22	142.38[1]	4.13	72.53	89.24	55.87

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[1] Two sheep only.

TABLE V. — COMPUTATION OF DIGESTION COEFFICIENTS — *Continued.*

SERIES XXI., ENGLISH HAY AND WHEAT GLUTEN FLOUR, PERIOD 4.[1]

Sheep VII.

ITEM.	Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
700 grams English hay fed, ...	621.95	40.99	47.21	203.19	312.77	17.79
40 grams wheat gluten fed, ...	37.18	.29	34.51	.03	2.20	.15
Amount consumed, ...	659.13	41.28	81.72	203.22	314.97	17.94
Minus 293.60 grams feces excreted, . .	278.48	26.20	25.84	84.71	131.70	10.03
Amount digested, ...	380.65	15.08	55.88	118.51	183.27	7.91
Minus 40 grams wheat gluten (assumed to be all digested).	37.18	.29	34.51	.03	2.20	.15
English hay digested, ...	343.47	14.79	21.37	118.48	181.07	7.76
Per cent. digested, ...	55.22	36.08	45.27	58.31	57.89	43.62

SERIES XXI., ENGLISH HAY, POTATO STARCH AND GLUTEN MEAL (DIAMOND), — GLUTEN MEAL (DIAMOND), PERIOD 5.

Sheep IV.

300 grams English hay fed, ...	269.61	18.52	20.03	91.05	132.95	7.06
125 grams potato starch fed, . . .	111.95	–	–	–	111.95	–
100 grams gluten meal (Diamond) fed, .	90.97	1.03	41.06	1.87	45.46	1.55
Amount consumed, ...	472.53	19.55	61.09	92.92	290.36	8.61
Minus 135.77 grams feces excreted, . .	126.67	15.76	17.64	33.21	56.23	5.83
Amount digested, ...	343.86	3.79	43.45	59.71	234.13	2.78
Minus hay and starch (100 per cent.) digested,	265.62	6.85	8.61	55.54	191.72	3.03
Gluten meal (Diamond) digested, . .	78.24	–	34.84	4.17	42.41	–
Per cent. ration digested, ...	72.77	19.38	71.12	64.26	80.63	32.29
Per cent. gluten meal (Diamond) digested, .	86.00	–	84.80	–	93.30	–

Sheep V.

Amount consumed as above, ...	472.53	19.55	61.09	92.92	290.36	8.61
Minus 113.25 grams feces excreted, . .	107.36	17.71	15.07	23.48	46.02	5.08
Amount digested, ...	365.17	1.84	46.02	69.44	244.34	3.53
Minus hay and starch (100 per cent.) digested,	265.62	6.85	8.61	55.54	191.72	3.03
Gluten meal (Diamond) digested, . .	99.55	–	37.41	13.90	52.62	.50
Per cent. ration digested, ...	77.28	9.41	75.33	74.73	84.15	41.00
Per cent. gluten meal (Diamond) digested, .	109.40	–	91.20	–	120.10	32.25

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[1] To note effect of wheat gluten flour.

TABLE V. — COMPUTATION OF DIGESTION COEFFICIENTS — *Continued.*

SERIES XXI., ENGLISH HAY, POTATO STARCH AND GLUTEN MEAL (DIAMOND), — GLUTEN MEAL (DIAMOND), PERIOD 5 — *Concluded.*

Sheep VI.

ITEM.	Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
Amount consumed as above,	472.53	19.55	61.09	92.92	290.36	8.61
Minus 132.14 grams feces excreted,	125.27	16.95	17.15	31.17	54.46	5.54
Amount digested,	347.26	2.60	43.94	61.75	235.90	3.07
Minus hay and starch (100 per cent.) digested,	265.62	6.85	8.61	55.54	191.72	3.03
Gluten meal (Diamond) digested,	81.64	–	35.33	6.21	44.18	–
Per cent. ration digested,	73.49	13.30	71.93	66.46	81.24	35.66
Per cent. gluten meal (Diamond) digested,	89.70	–	86.00	–	97.20	–
Average per cent. ration digested,	74.51	14.03	72.79	68.48	82.01	36.32
Average per cent. gluten meal (Diamond) digested.	95.03	–	87.33	–	70.20	32.25[1]

SERIES XXI., DISTILLERS' GRAINS, PERIOD 6.

Sheep IV.

300 grams English hay fed,	269.25	17.91	20.11	89.42	135.32	6.49
125 grams potato starch fed,	112.84	–	–	–	112.84	–
100 grams gluten meal (Diamond) fed,	91.06	1.06	41.09	2.03	45.17	1.71
200 grams distillers' grains fed,	193.74	4.48	51.15	28.50	91.40	18.21
Amount consumed,	666.89	23.45	112.35	119.95	384.73	26.41
Minus 196.28 grams feces excreted,	186.29	17.90	28.15	45.25	86.46	8.53
Amount digested,	480.60	5.55	84.20	74.70	298.27	17.88
Minus basal ration digested,	354.86	2.66	44.68	62.19	240.53	2.95
Distillers' grains digested,	125.74	2.89	39.52	12.51	57.74	14.93
Per cent. digested,	64.88	64.51	77.26	43.89	63.17	81.99

Sheep V.

Amount consumed as above,	666.89	23.45	112.35	119.95	384.73	26.41
Minus 190.84 grams feces excreted,	181.18	19.84	29.70	39.90	83.30	8.44
Amount digested,	485.71	3.61	82.65	80.05	301.43	17.97
Minus basal ration digested,	354.86	2.66	44.68	62.19	240.53	2.95
Distillers' grains digested,	130.85	.95	37.97	17.86	60.90	15.02
Per cent. digested,	67.54	21.21	74.23	62.67	66.63	82.48

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[1] One sheep only.

TABLE V. — COMPUTATION OF DIGESTION COEFFICIENTS — *Continued.*

SERIES XXI., DISTILLERS' GRAINS, PERIOD 6 — *Concluded.*

Sheep VI.

ITEM.	Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
Amount consumed as above,	666.89	23.45	112.35	119.95	384.73	26.41
Minus 189.96 grams feces excreted,	180.41	19.75	28.16	42.09	80.99	9.42
Amount digested,	486.48	3.70	84.19	77.86	303.74	16.99
Minus basal ration digested,	354.86	2.66	44.68	62.19	240.53	2.95
Distillers' grains digested,	131.62	1.04	39.51	15.67	63.21	14.04
Per cent. digested,	67.94	23.21	77.24	54.98	69.16	77.10
Average per cent. digested,	66.79	36.31	76.24	53.85	66.32	80.52

SERIES XXI., CORN BRAN, PERIOD 7.

Sheep IV.

300 grams English hay fed,	271.41	18.40	19.24	87.20	140.06	6.51
125 grams potato starch fed,	109.78	–	–	–	109.78	–
100 grams gluten meal fed,	91.55	.88	40.81	1.85	46.50	1.51
200 grams corn bran fed,	180.48	2.35	15.38	23.84	134.49	4.42
Amount consumed,	653.22	21.63	75.43	112.89	430.83	12.44
Minus 164.70 grams feces excreted,	157.47	14.74	22.55	36.25	77.19	6.74
Amount digested,	495.75	6.89	52.88	76.64	353.64	5.70
Minus basal ration digested,	354.56	2.70	43.84	60.55	243.00	2.89
Corn bran digested,	141.19	4.19	9.04	16.09	110.64	2.81
Per cent. digested,	78.23	178.29	58.78	67.49	82.27	63.57

Sheep V.

Amount consumed as above,	653.22	21.63	75.43	112.89	430.83	12.44
Minus 157.82 grams feces excreted,	150.86	14.92	28.12	29.43	71.72	6.67
Amount digested,	502.36	6.71	47.31	83.46	359.11	5.77
Minus basal ration digested,	354.56	2.70	43.89	60.55	243.00	2.89
Corn bran digested,	147.80	4.01	3.47	22.91	116.11	2.88
Per cent. digested,	81.89	170.63	22.56	96.10	86.33	65.16

TABLE V. — COMPUTATION OF DIGESTION COEFFICIENTS — *Continued.*

SERIES XXI., CORN BRAN, PERIOD 7 — *Concluded.*

Sheep VI.

ITEM.	Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
Amount consumed as above,	653.22	21.63	75.43	112.89	430.83	12.44
Minus 169.38 grams feces excreted,	162.10	18.75	22.08	40.61	74.58	6.08
Amount digested,	491.12	2.88	53.35	72.28	356.25	6.36
Minus basal ration digested,	354.56	2.70	43.84	60.55	243.00	2.89
Corn bran digested,	136.56	.18	9.51	11.73	113.25	3.47
Per cent. digested,	75.66	7.66	61.83	49.20	84.21	78.51
Average per cent. digested,	78.59	152.19	47.72	70.93	84.27	69.08

SERIES XXI., NEW BEDFORD GARBAGE TANKAGE, PERIOD 8.

Sheep IV.[1]

550 grams English hay fed,	497.86	34.65	36.19	167.93	246.00	13.09
150 grams gluten feed fed,	136.58	4.67	38.05	9.97	81.53	2.36
150 grams New Bedford garbage tankage fed,	137.21	21.57	30.21	13.27	69.87	2.29
Amount consumed,	771.65	60.89	104.45	191.17	397.40	17.74
Minus 286.48 grams feces excreted,	272.18	35.87	42.98	67.58	117.31	8.44
Amount digested,	499.47	25.02	61.47	123.59	280.09	9.30
Minus basal ration digested,	425.07	11.40	51.23	120.97	232.55	7.42
New Bedford garbage tankage digested,	74.40	13.62	10.24	2.62	47.54	1.88
Per cent. digested,	54.22	63.14	33.90	19.74	68.04	82.09

Sheep V.

550 grams English hay fed,	497.86	34.65	36.19	167.93	246.00	13.09
Minus 29.28 grams waste hay,	26.36	1.83	1.88	8.76	13.27	.62
English hay consumed,	471 50	32.82	34.31	159.17	232.73	12.47
150 grams gluten feed fed,	136.58	4.67	38.05	9.97	81.53	2.36
150 grams New Bedford garbage tankage fed,	137.21	21.57	30.21	13.27	69.87	2.29
Amount consumed,	745.29	59.06	102.57	182.41	384.13	17.12
Minus 244.60 grams feces excreted,	231.78	32.43	43.57	48.05	100.10	7.63
Amount digested,	513.51	26.63	59.00	134.36	284.03	9.49
Minus basal ration digested,	407.41	10.87	49.93	115.02	223.12	7.12
New Bedford garbage tankage digested,	106.10	15.76	9.07	19.34	60.91	2.37
Per cent. digested,	77.33	73.06	30.02	145.80	87.18	103.48

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[1] Excluded from average.

TABLE V. — COMPUTATION OF DIGESTION COEFFICIENTS — *Continued.*

SERIES XXI., NEW BEDFORD GARBAGE TANKAGE, PERIOD 8 — *Concluded.*

Sheep VI.

ITEM.	Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
Amount consumed as for Sheep IV., . .	771.65	60.89	104.45	191.17	397.40	17.74
Minus 247.68 grams feces excreted, . .	235.27	33.48	39.57	54.70	100.56	6.96
Amount digested, ...	536.38	27.41	64.88	136.47	296.84	10.78
Minus basal ration digested, . . .	425.07	11.40	51.23	120.97	232.55	7.42
New Bedford garbage tankage digested, .	111.31	16.01	13.65	15.50	64.29	3.36
Per cent. digested, ...	81.12	74.22	45.18	116.80	92.01	147.00
Average per cent. digested, . . .	79.22	73.64	37.60	131.30	89.60	125.24

SERIES XXI., ENGLISH HAY, PERIOD 9.

Sheep IX.

600 grams English hay fed, ...	533.40	37.66	39.95	172.66	268.89	14.24
Minus 14.24 grams waste, ...	14.01	1.29	.90	4.64	6.87	.31
Amount consumed, ...	519.39	36.37	39.05	168.02	262.02	13.93
Minus 228.28 grams feces excreted, . .	217.07	21.73	22.58	62.75	102.56	7.45
English hay digested, ...	302.32	14.64	16.47	105.27	159.46	6.48
Per cent. digested, ...	58.21	40.25	42.18	62.65	60.86	46.52

Sheep X.

600 grams English hay fed, ...	533.40	37.66	39.95	172.66	268.89	14.24
Minus 244.22 grams feces excreted, . .	232.72	21.29	21.25	70.17	111.59	8.42
English hay digested, ...	300.68	16.37	18.70	102.49	157.30	5.82
Per cent. digested, ...	56.37	43.47	46.81	59.36	58.50	40.87

Sheep XI.

600 grams English hay fed, ...	533.40	37.66	39.95	172.66	268.89	14.24
Minus 2.43 grams waste, ...	2.36	.27	.09	.85	1.12	.03
English hay consumed, ...	531.04	37.39	39.86	171.81	267.77	14.21
Minus 257.55 grams feces excreted, . .	245.24	23.13	23.89	74.80	114.79	8.63
English hay digested, ...	285.80	14.26	15.97	97.01	152.98	5.58
Per cent. digested, ...	53.82	38.14	40.07	56.46	57.13	39.27
Average per cent. digested, . . .	56.13	40.62	43.02	59.49	58.83	42.22

TABLE V. — COMPUTATION OF DIGESTION COEFFICIENTS — *Continued.*

SERIES XXI., ENGLISH HAY AND WHEAT GLUTEN FLOUR, PERIOD 10.[1]

Sheep IV.

ITEM.	Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
800 grams English hay fed,	714.96	49.55	52.26	235.29	359.20	18.66
Minus 60.57 grams waste,	60.57	4.20	4.43	19.93	30.43	1.58
English hay consumed,	654.39	45.35	47.83	215.36	328.77	17.08
50 grams wheat gluten fed,	47.48	.42	42.35	.04	3.88	.79
Minus 34.71 grams waste,	34.71	.31	30.95	.03	2.84	.58
Wheat gluten consumed,	12.77	.11	11.40	.01	1.04	.21
Amount consumed,	667.16	45.46	59.23	215.37	329.81	17.29
Minus 264.12 grams feces excreted,	252.60	24.30	25.51	74.01	118.27	10.51
Amount digested,	414.56	21.16	33.72	141.36	211.54	6.78
Minus wheat gluten digested,	12.77	.11	11.40	.01	1.04	.21
English hay digested,	401.79	21.05	22.32	141.35	210.50	6.57
Per cent. digested,	61.40	46.42	46.67	65.63	64.03	38.47

Sheep VI.

ITEM.	Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
800 grams English hay fed,	714.96	49.55	52.26	235.29	359.20	18.66
50 grams wheat gluten fed,	47.48	.42	42.35	.04	3.88	.79
Amount consumed,	762.44	49.97	94.61	235.33	363.08	19.45
Minus 288.47 grams feces excreted,	275.89	27.56	28.14	77.17	131.65	11.37
Amount digested,	486.55	22.41	66.47	158.16	231.43	8.08
Minus wheat gluten digested,	47.48	.42	42.35	.04	3.88	.79
English hay digested,	439.07	21.99	24.12	158.12	227.55	7.29
Per cent. digested,	61.41	44.38	46.15	67.20	63.35	39.07
Average per cent. digested,	61.41	45.40	46.41	66.42	63.69	38.77

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[1] To note effect of wheat gluten flour.

TABLE V. — COMPUTATION OF DIGESTION COEFFICIENTS — *Continued.*

SERIES XXI., ENGLISH HAY AND GLUTEN FEED, — GLUTEN FEED, PERIOD 11.

Sheep V.

ITEM.	Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
550 grams English hay fed,	499.40	42.65	50.94	152.27	240.01	13.53
150 grams gluten feed fed,	137.31	4.63	38.57	10.50	81.10	2.51
Amount consumed,	636.71	47.28	89.51	162.77	321.11	16.04
Minus 198.58 grams feces excreted,	187.88	28.13	26.55	42.63	82.38	8.19
Amount digested,	448.83	19.15	62.96	120.14	238.73	7.85
Minus hay digested,	294.65	15.78	27.00	95.93	153.60	6.90
Gluten feed digested,	154.18	3.37	35.96	24.21	85.13	.95
Per cent. ration digested,	70.49	40.50	70.34	73.81	74.35	48.94
Per cent. gluten feed digested,	112.30	73.00	93.20	231.00	105.00	38.00

Sheep VI.

Amount consumed as above,	636.71	47.28	89.51	162.77	321.11	16.04
Minus 193.37 grams feces excreted,	183.55	30.78	25.79	39.61	79.50	7.87
Amount digested,	453.16	16.50	63.72	123.16	241.61	8.17
Minus hay digested,	294.65	15.78	27.00	95.93	153.60	6.90
Gluten feed digested,	158.51	.72	36.72	27.23	88.01	1.27
Per cent. ration digested,	71.17	34.90	71.19	75.67	75.24	50.94
Per cent. gluten feed digested,	115.40	15.00	95.10	259.00	108.50	51.00
Average per cent. ration digested,	70.83	37.70	70.77	74.74	74.80	49.94
Average per cent. gluten feed digested,	113.85	44.00	94.15	245.00	106.75	44.50

SERIES XXI., FETERITA, PERIOD 12.

Sheep V.

550 grams English hay fed,	495.94	41.96	47.86	151.61	240.97	13.54
150 grams gluten feed fed,	137.25	4.68	38.35	10.14	81.94	2.14
200 grams feterita fed,	179.18	3.23	23.71	2.51	143.75	5.98
Amount consumed,	812.37	49.87	109.92	164.26	466.66	21.66
Minus 244.74 grams feces excreted,	229.57	35.51	35.72	49.56	98.59	10.19
Amount digested,	582.80	14.36	74.20	114.70	368.07	11.47
Minus hay and gluten feed digested,	449.56	17.72	61.21	121.31	242.18	7.84
Feterita digested,	133.24	–	12.99	–	125.89	3.63
Per cent. digested,	74.36	–	54.79	–	87.58	60.70

TABLE V. — COMPUTATION OF DIGESTION COEFFICIENTS — *Continued.*

SERIES XXI., FETERITA, PERIOD 12 — *Concluded.*

Sheep VI.

ITEM.	Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
Amount consumed as above,	812.37	49.87	109.92	164.26	466.66	21.66
Minus 243.61 grams feces excreted,	228.55	32.25	39.63	48.43	97.57	10.67
Amount digested,	583.82	17.62	70.29	115.83	396.09	10.99
Minus hay and gluten feed digested,	449.56	17.72	61.21	121.31	242.18	7.84
Feterita digested,	134.26	-	9.08	-	126.91	3.15
Per cent. digested,	74.93	-	38.30	-	88.29	52.68
Average per cent. digested,	74.65	-	46.55	-	87.94	56.69

SERIES XXI., ENGLISH HAY, PERIOD 13.

Sheep XII.

700 grams English hay fed,	634.55	52.48	57.87	197.09	309.85	17.26
Minus 259.31 grams feces excreted,	243.98	31.96	26.15	68.39	109.38	8.10
English hay digested,	390.57	20.52	31.72	128.70	200.47	9.16
Per cent. digested,	60.69	39.10	54.81	65.30	64.70	53.07

Sheep XIII.

700 grams English hay fed,	634.55	52.48	57.87	197.09	309.85	17.26
Minus 6.43 grams waste,	6.23	.38	.27	2.54	2.98	.06
Amount consumed,	628.32	52.10	57.60	194.55	306.87	17.20
Minus 266.30 grams feces excreted,	250.38	33.40	26.49	72.71	108.97	8.81
English hay digested,	377.94	18.70	31.11	121.84	197.90	8.39
Per cent. digested,	60.15	35.89	54.01	62.63	64.49	48.78

Sheep XIV.

700 grams English hay fed,	634.55	52.48	57.87	197.09	309.85	17.26
Minus 280.22 grams feces excreted,	263.60	33.95	28.42	76.73	115.91	8.59
English hay digested,	370.95	18.53	29.45	120.36	193.94	8.67
Per cent. digested,	57.64	35.31	50.89	61.07	62.59	50.23
Average per cent. digested,	59.49	36.77	53.24	63.00	63.93	50.69

TABLE V. — COMPUTATION OF DIGESTION COEFFICIENTS — *Continued.*

SERIES XXI., SWEET CLOVER (GREEN), PERIOD 14.

Sheep IV.

ITEM.	Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
500 grams English hay fed,	442.15	35.81	39.93	138.13	216.17	12.11
1,600 grams sweet clover,	264.80	25.31	45.89	89.50	96.53	7.57
Amount consumed,	706.95	61.12	85.82	227.63	312.70	19.68
Minus 302.46 grams feces excreted,	274.48	35.74	30.11	86.41	112.50	9.72
Amount digested,	432.47	25.38	55.71	141.22	200.20	9.96
Minus hay digested,	260.87	13.25	21.16	87.02	138.35	6.18
Sweet clover digested,	171.60	12.13	34.55	54.20	61.85	3.78
Per cent. digested,	64.80	47.93	75.29	60.56	64.07	49.91

Sheep VI.

1,600 grams sweet clover fed,	264.80	25.31	45.89	89.50	96.53	7.57
Minus 26.14 grams waste,	24.94	2.27	2.47	11.78	8.11	.31
Sweet clover consumed,	239.86	23.04	43.42	77.72	88.42	7.26
500 grams English hay consumed,	442.15	35.81	39.93	138.13	216.17	12.11
Amount consumed,	682.01	58.85	83.35	215.85	304.59	19.37
Minus 270.07 grams feces excreted,	245.33	34.32	28.07	72.59	100.81	9.54
Amount digested,	436.68	24.53	55.28	143.26	203.78	9.83
Minus hay digested,	260.87	13.25	21.16	87.02	138.35	6.18
Sweet clover digested,	175.81	11.28	34.12	56.24	65.43	3.65
Per cent. digested,	73.30	48.96	78.58	72.36	74.00	50.28
Average per cent. digested,	69.05	48.45	76.94	66.46	69.04	50.10

SERIES XXII., SUDAN GRASS (GREEN, SECOND CROP), PERIOD 1.

Sheep IV.

500 grams English hay fed,	433.50	33.42	39.75	131.31	218.05	10.97
1,600 grams Sudan grass (green, fourth cutting) fed.	367.00	24.44	44.29	104.79	190.67	11.81
Amount consumed,	809.50	57.86	84.04	236.10	408.72	22.78
Minus 316.87 grams feces excreted,	294.78	39.71	35.93	72.78	135.72	10.64
Amount digested,	514.72	18.15	48.11	163.32	273.00	12.14
Minus hay digested,	268.77	9.36	20.27	90.60	143.91	4.52
Sudan grass digested,	245.95	8.79	27.84	72.72	129.09	7.64
Per cent. digested,	65.41	37.97	62.86	69.40	67.70	64.69

Table V. — Computation of Digestion Coefficients — *Continued.*

Series XXII., Sudan Grass (Green, Second Crop), Period 1 — *Concluded.*

Sheep VI.

Item.	Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
Amount consumed as above,	809.50	57.86	84.04	236.10	408.72	22.78
Minus 318.78 grams feces excreted,	295.99	42.56	33.62	72.75	135.68	11.37
Amount digested,	513.51	15.30	50.42	163.35	273.04	11.41
Minus hay digested,	268.77	9.36	20.27	90.60	143.91	4.50
Sudan grass digested,	244.74	5.94	30.15	72.75	129.13	6.91
Per cent. digested,	65.09	24.30	68.07	69.42	67.69	58.51
Average per cent. digested,	65.25	30.14	65.47	69.41	67.70	61.60

Series XXII., English Hay, Period 2.

Sheep IV.

800 grams English hay fed,	685.36	52.02	59.28	218.84	337.75	17.48
Minus 285.59 grams feces excreted,	265.88	36.77	27.49	70.96	120.34	10.32
English hay digested,	419.48	15.25	31.79	147.88	217.41	7.16
Per cent. digested,	61.21	29.31	53.63	67.57	64.37	40.96

Sheep VI.

Amount consumed as above,	685.36	52.02	59.28	218.84	337.75	17.48
Minus 276.71 grams feces excreted,	256.90	38.18	30.85	65.18	112.32	10.38
English hay digested,	428.46	13.84	28.43	153.66	225.43	7.10
Per cent. digested,	62.52	26.61	47.96	70.21	66.75	40.62
Average per cent. digested,	61.87	27.96	50.80	68.89	65.56	40.79

Series XXII., Sudan Grass (Dry, Second Crop), Period 3.

Sheep IV.

400 grams English hay fed,	353.00	28.45	33.43	107.49	174.63	9.00
500 grams Sudan grass (dry, fourth cutting) fed.	390.60	33.55	53.00	129.99	167.68	6.37
Amount consumed,	743.60	62.00	86.43	237.48	342.31	15.37
Minus 309.29 grams feces excreted,	290.42	38.92	38.57	67.61	135.92	9.41
Amount digested,	453.18	23.08	47.86	169.87	206.39	5.96
Minus hay digested,	218.86	7.96	17.05	74.17	115.26	3.69
Sudan grass digested,	234.32	15.12	30.81	95.70	91.13	2.27
Per cent. digested,	59.99	45.07	58.13	73.62	54.35	35.63

TABLE V. — COMPUTATION OF DIGESTION COEFFICIENTS — *Continued.*

SERIES XXII., SUDAN GRASS (DRY, SECOND CROP), PERIOD 3 — *Concluded.*

Sheep VI.

ITEM.	Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
Amount consumed as above,	743.60	62.00	86.43	237.48	342.31	15.37
Minus 313.86 grams feces excreted,	292.83	40.53	36.84	68.73	137.31	9.43
Amount digested,	450.77	21.47	49.59	168.75	205.00	5.94
Minus hay digested,	218.86	7.96	17.05	74.17	115.26	3.69
Sudan grass digested,	321.91	13.51	32.54	94.58	89.74	2.25
Per cent. digested,	59.37	40.27	61.40	72.76	53.52	35.32
Average per cent. digested,	59.68	42.67	59.77	73.19	53.94	35.48

SERIES XXII., SUDAN GRASS (FIRST CROP, THIRD CUTTING), PERIOD 4.

Sheep IX.

ITEM.	Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
700 grams Sudan grass (third cutting, dry) fed.	616.00	45.40	73.24	220.47	268.02	8.87
Minus 270.21 grams feces excreted,	258.02	21.11	27.56	74.23	130.04	5.08
Sudan grass digested,	357.98	24.29	45.68	146.24	137.98	3.79
Per cent. digested,	58.11	53.50	62.37	66.33	51.48	42.73

Sheep XI.

ITEM.	Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
700 grams Sudan grass (third cutting, dry) fed.	616.00	45.40	73.24	220.47	268.02	8.87
Minus 292.87 grams feces excreted,	278.93	26.22	30.96	77.60	138.32	5.80
Sudan grass digested,	337.07	19.18	42.28	142.87	129.70	3.07
Per cent. digested,	54.72	42.25	47.73	64.80	48.39	34.61
Average per cent. digested,	56.42	47.88	60.05	65.57	49.94	38.67

SERIES XXII., SUDAN GRASS (FIRST CROP, SECOND CUTTING), PERIOD 6.

Sheep IX.

ITEM.	Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
700 grams Sudan grass (second cutting, dry) fed.	616.49	59.61	95.49	205.41	246.53	9.43
Minus 266.71 grams feces excreted,	251.56	26.54	34.03	64.90	119.29	6.79
Sudan grass digested,	364.93	33.07	61.46	140.51	127.24	2.64
Per cent. digested,	59.19	55.48	64.36	68.40	51.57	28.00

TABLE V. — COMPUTATION OF DIGESTION COEFFICIENTS — *Continued.*

SERIES XXII., SUDAN GRASS (FIRST CROP, FIRST CUTTING), PERIOD 7.

Sheep XI.

ITEM.	Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
700 grams Sudan grass (first cutting, dry) fed,	615.44	61.97	88.93	204.33	250.73	9.48
Minus 5.57 grams of waste,	5.23	.69	.49	2.15	1.84	.05
Amount consumed,	610.21	61.28	88.44	202.18	248.89	9.43
Minus 283.26 grams feces excreted,	266.94	27.01	38.36	67.96	126.34	7.26
Sudan grass (first cutting) digested,	343.27	34.27	50.08	134.22	122.55	2.17
Per cent. digested,	56.25	55.92	56.63	66.38	49.24	23.01

Sheep XII.

700 grams Sudan grass (first cutting, dry) fed,	615.44	61.97	88.93	204.33	250.73	9.48
Minus 94.43 grams of waste,	81.92	10.78	9.72	29.42	31.09	.91
Amount consumed,	533.52	51.19	79.21	174.91	219.64	8.57
Minus 253.21 grams feces excreted,	239.33	24.87	35.47	58.73	112.58	7.68
Sudan grass (first cutting) digested,	294.19	26.32	43.74	116.18	107.06	.89
Per cent. digested,	55.14	51.42	55.22	66.42	48.74	10.38

Sheep XIII.

700 grams Sudan grass (first cutting, dry) fed,	615.44	61.97	88.93	204.33	250.73	9.48
Minus 278.76 grams feces excreted,	263.73	26.69	37.50	67.80	124.11	7.62
Sudan grass (first cutting) digested,	351.71	35.28	51.43	136.53	126.62	1.86
Per cent. digested,	57.15	56.93	57.83	66.82	50.51	19.62
Average per cent. digested,	56.18	54.76	56.56	66.54	49.50	17.67

SERIES XXII., ENGLISH HAY, PERIOD 8.

Sheep IV.

800 grams English hay fed,	719.36	49.28	59.35	236.60	357.23	16.90
Minus 295.57 grams feces excreted,	279.11	29.20	29.50	77.65	133.42	9.35
English hay digested,	440.25	20.08	29.85	158.95	223.81	7.55
Per cent. digested,	61.20	40.75	50.30	67.18	62.65	44.67

Table V. — Computation of Digestion Coefficients — *Continued.*

Series XXII., English Hay, Period 8 — *Concluded.*

Sheep VI.

Item.	Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
800 grams English hay fed,	719.36	49.28	59.35	236.60	357.23	16.90
Minus 282.37 grams feces excreted,	266.70	28.51	28.86	72.62	127.51	9.20
English hay digested,	442.66	20.77	30.49	163.98	229.72	7.70
Per cent. digested,	61.54	42.15	51.37	69.31	64.31	45.56
Average per cent. digested,	61.37	41.45	50.84	68.25	63.48	45.12

Series XXII., Vinegar Grains, Period 9.

Sheep IX.

250 grams vinegar grains fed,	230.55	5.79	47.40	46.41	116.01	14.94
550 grams English hay fed,	495.72	35.59	41.49	167.55	239.18	11.90
Amount consumed,	726.27	41.38	88.89	213.96	355.19	26.84
Minus 309.94 grams feces excreted,	297.60	27.14	37.91	78.21	145.44	8.90
Amount digested,	428.67	14.24	50.98	135.75	209.75	17.94
Minus English hay digested,	302.39	14.59	21.16	113.93	150.68	5.36
Vinegar grains digested,	126.28	–	29.82	21.82	59.07	12.58
Per cent. digested,	54.77	–	62.91	47.02	50.92	84.20

Sheep XI.

Amount consumed as above,	726.27	41.38	88.89	213.96	355.19	26.84
Minus 318.83 grams feces excreted,	297.05	29.11	39.63	76.55	143.45	8.32
Amount digested,	429.22	12.27	49.26	137.41	211.74	18.52
Minus English hay digested,	302.39	14.59	21.16	113.93	150.68	5.36
Vinegar grains digested,	126.83	–	28.10	23.48	61.06	13.16
Per cent. digested,	55.01	–	59.28	50.59	52.63	88.08
Average per cent. digested,	54.89	–	61.10	48.80	51.77	86.14

TABLE V. — COMPUTATION OF DIGESTION COEFFICIENTS — *Continued.*

SERIES XXII., VINEGAR GRAINS, PERIOD 10.

Sheep IV.

ITEM.	Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
250 grams vinegar grains fed,	231.33	5.95	46.77	46.54	116.45	15.61
550 grams English hay fed,	495.00	36.23	43.07	159.10	244.33	12.18
Amount consumed,	726.33	42.18	89.84	205.64	360.78	27.79
Minus 285.43 grams feces excreted,	272.59	25.60	35.38	69.10	143.14	8.37
Amount digested,	453.74	16.58	54.46	136.54	217.64	19.42
Minus English hay digested,	301.95	14.85	21.97	108.19	153.93	5.48
Vinegar grains digested,	151.79	1.73	32.49	28.35	63.71	13.94
Per cent. digested,	65.60	29.08	69.47	60.92	54.71	89.30

Sheep VI.

Amount consumed as above,	726.33	42.18	89.84	205.64	360.78	27.79
Minus 281.57 grams feces excreted,	268.28	28.97	37.00	63.07	130.46	8.77
Amount digested,	458.05	13.21	52.84	142.57	230.32	19.02
Minus English hay digested,	301.95	14.85	21.97	108.19	153.93	5.48
Vinegar grains digested,	156.10	–	30.87	34.38	76.39	13.54
Per cent. digested,	67.48	–	66.00	73.87	65.60	86.70
Average per cent. digested,	66.54	29.08[1]	67.74	67.40	59.66	88.00

SERIES XXII., STEVENS' "44" DAIRY RATION, PERIOD 11.

Sheep IV.

250 grams of Stevens' "44" Dairy Ration fed,	227.65	9.49	61.35	29.32	112.82	14.66
550 grams English hay fed,	499.13	33.69	41.08	164.56	247.47	12.33
Amount consumed,	726.78	43.18	102.43	193.88	360.29	26.99
Minus 269.57 grams feces excreted,	257.14	26.90	31.09	68.68	122.50	7.97
Amount digested,	469.64	16.28	71.34	125.20	237.79	19.02
Minus English hay digested,	304.47	13.81	20.95	111.90	155.90	5.55
Stevens' "44" Dairy Ration digested,	165.17	2.47	50.39	13.30	81.89	13.47
Per cent. digested,	72.55	26.03	82.14	45.36	72.58	91.88

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[1] One sheep only.

TABLE V. — COMPUTATION OF DIGESTION COEFFICIENTS — *Continued.*

SERIES XXII., STEVENS' "44" DAIRY RATION, PERIOD 11 — *Concluded.*

Sheep VI.

ITEM.	Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
Amount consumed as above,	726.78	43.18	102.43	193.88	360.29	26.99
Minus 277.79 grams feces excreted,	266.18	30.93	34.10	65.85	126.28	9.02
Amount digested,	460.60	12.25	68.33	128.03	234.01	15.97
Minus English hay digested,	304.47	13.81	20.95	111.90	155.90	5.55
Stevens' "44" Dairy Ration digested,	156.13	–	47.38	16.13	78.11	10.42
Per cent. digested,	68.58	–	77.23	55.01	69.23	71.08
Average per cent. digested,	70.57	26.03[1]	79.69	50.19	70.91	81.48

SERIES XXII., NEW YORK ALFALFA (THIRD CUTTING), PERIOD 2.

Sheep IV.

800 grams New York alfalfa (third cutting) fed.	700.96	42.27	105.92	248.28	291.11	13.39
Minus 306.21 grams feces excreted,	293.69	24.73	28.43	131.78	97.59	11.16
Alfalfa digested,	407.27	17.54	77.49	116.50	193.52	2.23
Per cent. digested,	58.10	41.50	73.16	46.92	66.48	16.66

Sheep VI.

800 grams New York alfalfa (third cutting) fed.	700.96	42.27	105.92	248.28	291.11	13.39
Minus 4.57 grams waste,	4.14	.17	.27	2.19	1.47	.03
Amount consumed,	696.82	42.10	105.65	246.09	289.64	13.36
Minus 330.53 grams feces excreted,	315.33	30.27	33.61	134.99	105.13	11.32
Alfalfa digested,	381.49	11.83	20.04	111.10	184.51	2.04
Per cent. digested,	54.75	28.10	68.19	45.15	63.70	15.27
Average per cent. digested,	56.43	34.80	70.68	46.04	65.09	15.97

SERIES XXII., ENGLISH HAY, PERIOD 13.

Sheep XII.

700 grams English hay fed,	636.09	45.73	51.78	211.56	311.81	15.20
Minus 268.70 grams feces excreted,	256.15	23.54	24.23	78.46	121.20	8.68
English hay digested,	379.94	22.19	27.55	133.10	190.61	6.52
Per cent. digested,	59.73	48.52	53.20	62.91	61.13	41.89

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[1] One sheep only.

TABLE V. — COMPUTATION OF DIGESTION COEFFICIENTS — *Continued.*

SERIES XXII., ENGLISH HAY, PERIOD 13 — *Concluded.*

Sheep XIII.

ITEM.	Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
700 (minus 1.67 grams waste) equals 698.33 grams English hay fed.	634.57	45.63	51.65	211.06	311.07	15.17
Minus 281.36 grams feces excreted, . .	266.79	25.43	26.68	80.12	125.87	8.70
English hay digested, ...	367.78	20.20	24.97	130.94	185.20	6.47
Per cent. digested, ...	57.96	44.27	48.37	72.04	57.54	42.65
Average per cent. digested, . . .	58.85	46.40	50.77	62.48	60.34	42.77

SERIES XXII., NEW YORK ALFALFA (THIRD CUTTING), PERIOD 14.

Sheep XII.

700 grams New York alfalfa (third cutting) fed.	638.75	44.37	99.45	221.65	260.10	13.16
Minus 269.07 grams feces excreted, . .	257.96	22.13	27.42	114.64	84.59	9.18
Alfalfa digested, ...	380.79	22.26	72.03	107.01	175.51	3.98
Per cent. digested, ...	59.61	50.15	72.43	48.28	67.48	30.24

Sheep XIII.

700 grams New York alfalfa (third cutting) fed.	638.75	44.37	99.45	221.65	260.10	13.16
Minus 277.50 grams feces excreted, . .	265.04	21.89	26.53	121.39	86.32	8.91
Alfalfa digested, ...	373.71	22.50	72.92	100.26	173.78	4.25
Per cent. digested, ...	58.50	50.68	73.32	45.23	66.81	32.29
Average per cent. digested, . . .	59.06	50.42	72.88	46.76	67.15	31.26

SERIES XXII., ROWEN, PERIOD 15.

Sheep XII.

700 grams rowen fed, ...	636.09	51.65	82.88	179.06	300.80	21.69
Minus 259.10 grams feces excreted, . .	249.25	33.97	32.83	57.08	110.19	15.18
Rowen digested, ...	386.84	17.68	50.05	121.98	190.61	6.51
Per cent. digested, ...	60.81	34.23	60.39	68.12	63.37	30.01

Sheep XIII.

700 grams rowen fed, ...	636.09	51.65	82.88	179.06	300.80	21.69
Minus 257.74 grams feces excreted, . .	247.04	33.18	32.93	57.17	109.56	14.20
Rowen digested, ...	389.05	18.47	49.95	121.89	191.24	7.49
Per cent. digested, ...	61.16	35.76	60.27	68.08	63.57	34.53
Average per cent. digested, . . .	60.99	35.00	60.33	68.10	63.47	32.27

TABLE V. — COMPUTATION OF DIGESTION COEFFICIENTS — *Continued.*

SERIES XXII., SWEET CLOVER (GREEN), PERIOD 16.

Sheep IX.

ITEM.	Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
400 grams English hay fed,	359.48	25.92	32.57	109.03	182.04	9.92
1,600 grams sweet clover fed,	232.00	10.67	49.79	62.13	101.52	7.89
Amount consumed,	591.48	36.59	82.36	171.16	283.56	17.81
Minus 246.07 grams feces excreted,	228.30	27.36	28.67	72.71	107.38	9.94
Amount digested,	363.18	9.23	53.69	98.45	176.18	7.87
Minus hay digested,	208.50	11.66	15.63	68.89	109.22	4.46
Sweet clover digested,	154.68	–	38.06	29.56	66.96	3.41
Per cent. sweet clover digested,	66.67	–	76.44	47.60	65.96	43.22

Sheep XI.

Amount consumed as above,	591.48	36.59	82.36	171.16	283.56	17.81
Minus 231.36 grams feces excreted,	214.52	24.89	25.91	69.78	102.26	8.51
Amount digested,	376.96	11.70	56.45	101.38	181.30	9.30
Minus hay digested,	208.50	11.66	15.63	68.89	109.22	4.46
Sweet clover digested,	168.46	.04	40.82	32.49	72.08	4.84
Per cent. sweet clover digested,	72.61	.03	81.98	52.29	71.00	61.34
Average per cent. sweet clover digested,	69.64	.03	79.21	49.95	68.48	52.28

SERIES XXII., SUDAN GRASS (GREEN), PERIOD 17.

Sheep XII.

400 grams English hay fed,	352.28	24.69	30.79	117.63	169.27	9.90
1,600 grams Sudan grass (green, first cutting) fed.	313.28	22.49	44.58	95.02	136.43	14.75
Amount consumed,	665.56	47.18	75.37	212.65	305.70	24.65
Minus 235.01 grams feces excreted,	215.74	16.27	24.18	58.53	109.14	7.62
Amount digested,	449.82	30.91	51.19	154.12	196.56	17.03
Minus hay digested,	207.85	11.36	15.70	72.93	101.56	4.26
Sudan grass (green, first cutting) digested,	241.97	19.55	35.49	81.19	95.00	12.77
Per cent. Sudan grass (green, first cutting) digested.	77.23	86.93	79.61	85.45	69.63	86.57

TABLE V. — COMPUTATION OF DIGESTION COEFFICIENTS — *Concluded.*

SERIES XXII., SUDAN GRASS (GREEN), PERIOD 17 — *Concluded.*

Sheep XIII.

ITEM.	Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
Amount consumed as above,	665.56	47.18	75.37	212.65	305.70	24.65
Minus 253.04 grams feces excreted,	235.78	26.83	24.38	65.90	110.13	8.54
Amount digested,	429.78	20.35	50.99	146.75	195.57	16.11
Minus hay digested,	207.85	11.36	15.70	72.93	101.56	4.26
Sudan grass (green, first cutting) digested,	221.93	8.99	35.29	73.82	94.01	11.85
Per cent. Sudan grass (green, first cutting) digested.	70.84	39.96	79.16	77.69	68.97	80.34
Average per cent. Sudan grass (green, first cutting) digested.	74.04	63.45	79.38	81.57	69.30	83.46

DISCUSSION OF THE RESULTS.

Having presented in the foregoing pages a statement of the general purpose of these experiments, an explanation of the tables, and the data of the composition of the feeds and feces, as well as the detailed data of the experiments, including the computation of the digestion coefficients, it is intended in the pages which follow to state briefly the general character of each feed, summarize the coefficients secured, and draw such conclusions as the results indicate.

In noting the variations which occur when the same feed is fed to different sheep, the fact must not be lost sight of that digestibility is made up of a number of processes. Armsby states the matter clearly when he says "digestibility in ruminants is a very complex affair, depending on many factors; . . . it may be characterized as a series of fermentations effected in part by a variety of organized ferments, and in part by enzymes secreted by the digestive organs or contained in the feed itself. Changes in the composition of the contents of the digestive tract, or in the rapidity with which they move forward through it, can hardly fail to influence in a variety of ways the course of these fermentations, and it seems, on the whole, rather surprising that they go forward as rapidly as they do."

Summary of Coefficients of English Hay — Basal.

Lot.	Series.	Period.	Sheep.	Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
1	XIX.	3	I.	59.77	20.59	49.08	64.84	64.07	38.42
1	XIX.	3	II.	57.65	23.90	53.12	58.93	62.39	38.17
1	XIX.	9	V.	60.57	33.50	53.53	63.32	63.29	57.47
1	XIX.	9	VI.	57.53	32.81	51.10	58.66	60.84	54.99
Average, ...				58.88	27.70	51.71	61.45	62.72	47.26
2	XX.	1	I.	64.70	39.69	50.86	70.41	66.78	84.67
2	XX.	1	II.	63.43	36.98	50.38	68.33	66.06	47.96
2	XX.	6	IV.	60.08	42.04	48.34	63.10	62.51	39.26
2	XX.	10	VII.	56.80	42.70	52.25	59.57	58.27	43.15
2	XX.	10	VIII.	59.70	44.21	52.72	62.44	61.96	41.83
Average, ...				60.94	41.12	50.91	64.77	63.12	51.39
3	XXI.	2	VII.	54.89	28.25	42.00	58.88	58.62	42.44
3	XXI.	2	VIII.	61.70	37.65	45.08	68.06	64.39	44.65
3	XXI.	9	IX.	58.21	40.25	42.18	62.65	60.86	46.52
3	XXI.	9	X.	56.37	43.47	46.81	59.36	58.50	40.87
3	XXI.	9	XI.	53.82	38.14	40.07	56.46	57.13	39.27
Average, ...				57.00	37.55	43.23	61.08	59.90	42.71
4	XXI.	13	XII.	60.69	39.10	54.81	65.30	64.70	53.07
4	XXI.	13	XIII.	60.15	35.89	54.01	62.63	64.49	48.78
4	XXI.	13	XIV.	57.64	35.31	50.89	61.07	62.59	50.23
4	XXII.	2	IV.	61.21	29.31	53.63	67.57	64.37	40.96
4	XXII.	2	VI.	62.52	26.61	47.96	70.21	66.75	40.62
Average, ...				60.44	31.24	52.26	65.36	64.58	46.73
5	XXII.	8	IV.	61.20	40.75	50.30	67.18	62.65	44.67
5	XXII.	8	VI.	61.54	42.15	51.37	69.31	64.31	45.56
5	XXII.	13	XII.	59.73	48.52	53.20	62.91	61.13	41.89
5	XXII.	13	XIII.	57.96	44.27	48.37	72.04	57.54	42.65
Average, ...				60.11	43.92	50.81	67.86	61.41	43.69
Grand average, ...				59.47	36.31	49.78	64.10	62.35	46.34

Five distinct lots of hay were used in these experiments. The hay was cut when in bloom from an old mowing, and was composed largely of Kentucky blue grass (*Poa pratensis*) and sweet vernal grass (*Anthoxanthum odoratum*) with an admixture of more or less clover. The results, on the whole, are reasonably uniform, although one notes occasional variations, particularly in the fiber and also in the protein, due evidently to the individuality and perhaps to particular condition of the sheep.

The last two lots were evidently of somewhat better quality, or perhaps cut a little earlier than the first two, for they showed a somewhat superior digestibility. All five lots were more fully digested than is timothy hay. Note that the fiber in the hay has a digestibility slightly above the extract matter. This is characteristic of many coarse feeds.

Summary of Coefficients of English Hay and Gluten Feed — Basal.

Lot.		Series.	Period.	Sheep.	Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
Hay.	Gluten Feed.									
1	1	XIX.	2	V.	66.13	34.59	67.91	64.67	69.82	56.13
1	1	XIX.	2	VI.	66.61	27.03	68.79	66.60	70.21	56.53
1	2	XIX.	15	V.	66.70	42.45	64.22	66.36	70.29	54.23
1	2	XIX.	15	VI.	66.22	39.97	59.69	60.35	66.48	48.23
2	2	XX.	5	I.	70.34	41.09	66.45	74.12	72.80	60.56
2	2	XX.	5	II.	66.69	28.84	61.42	69.60	70.70	58.33
2	2	XX.	14	IV.	60.31	27.12	63.45	60.34	63.53	50.95
2	2	XX.	14	V.	63.23	29.01	64.01	65.99	66.05	46.73
2	2	XX.	14	VI.	63.74	31.94	64.71	65.92	66.31	51.93
3	3	XXI.	1	IV.	64.97	31.78	68.38	65.52	68.73	46.03
3	3	XXI.	1	V.	66.92	23.83	68.53	68.50	71.74	47.76
3	3	XXI.	1	VI.	68.81	32.51	70.34	71.07	72.53	49.21
4	3	XXI.	11	V.	70.49	40.50	70.34	73.81	74.35	48.94
4	3	XXI.	11	VI.	71.17	34.90	71.19	75.67	75.24	50.94
Average, ...					66.59	33.25	66.39	67.75	69.91	51.89

In many cases it was thought wise to use a basal ration composed of English hay and gluten feed in order to secure a combination better balanced as regards protein and carbohydrates than is hay. Gluten feed was selected to be used with the hay because it contained a moderate amount of protein and is usually quite fully digested. In Series XIX. a combination of 650 grams of hay and 125 grams of gluten feed was used, and in the other cases 550 grams of hay and 150 grams of gluten feed.

The results of Period 14, Series XX., are rather surprising, and in a way hardly to be explained, being noticeably below Series XXI., Periods 1 and 11, which are reasonably uniform. They will be discussed further in considering the digestibility of gluten feed. Series XIX., Period 15, has more hay in proportion to gluten feed, and the coefficients are somewhat below the other series, with the exceptions mentioned.

Summary of Coefficients of English Hay, Potato Starch and Diamond Gluten Meal — Basal.

Lot.		Series.	Period.	Sheep.	Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
Hay.	Starch and Gluten.									
1	1	XIX.	10	III.	73.45	33.70	73.48	59.62	80.71	34.29
1	1	XIX.	10	IV.	70.47	13.22	71.02	55.41	78.91	32.67
1	1	XIX.	11	IV.	72.17	33.93	75.02	60.73	78.39	47.07
2	1	XXI.	5	IV.	72.77	19.38	71.12	64.26	80.63	32.29
2	1	XXI.	5	V.	77.28	9.41	75.33	74.73	84.15	41.00
2	1	XXI.	5	VI.	73.49	13.30	71.93	66.46	81.24	35.66
Average,					73.27	20.16	72.98	63.54	80.67	37.16

In order to study the digestibility of fiber in distillers' grains and corn bran, a basal ration composed of a limited amount of hay plus potato starch and Diamond gluten meal was used. This ration naturally contained but little fiber, and would permit the intestinal juices and ferments to exert their maximum effect upon the fiber of the two by-products.

Sheep IV. in Series XIX. received 100 grams more hay and 25 grams more gluten meal daily in the combination than did the other three sheep. The coefficients of this basal ration are fairly uniform, excepting that Sheep V. appeared to have digested noticeably more of the ration than did the other sheep.

Summary of Coefficients of Gluten Feed (Present Experiments).

Series.	Period.	Sheep.	Brand.	Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
XIX.	2	V.	–	91.80	167.00	87.50	99.00	94.70	72.50
XIX.	2	VI.	–	94.70	–	89.50	126.00	96.30	73.60
XIX.	14	V.	–	112.09	337.98	84.78	208.85	110.89	59.91
XIX.	14	VI.	–	94.54	258.91	89.69	116.36	94.63	53.50
XIX.	15	V.	Clinton	106.57	163.22	82.62	173.28	108.91	50.00
XIX.	15	VI.	Clinton	78.90	129.89	71.28	47.41	87.34	29.55
XX.	5	I.	Clinton	93.42	75.66	84.70	145.65	94.25	87.60
XX.	5	II.	Clinton	76.50	–	73.73	77.96	85.50	80.45
XX.	14	IV.	Clinton	50.38	–	76.15	–	58.65	63.55
XX.	14	V.	Clinton	64.07	–	77.25	51.82	69.51	50.32
XX.	14	VI.	Clinton	66.47	–	78.61	50.80	70.63	66.01
XXI.	1	IV.	Buffalo	93.87	–	92.96	136.00	95.88	63.27
XXI.	1	V.	Buffalo	102.79	–	93.16	185.00	108.12	74.69
XXI.	1	VI.	Buffalo	111.63	–	96.82	228.00	111.46	84.49
XXI.	11	V.	Buffalo	112.30	73.00	93.20	231.00	105.00	38.00
XXI.	11	VI.	Buffalo	115.40	15.00	95.10	259.00	108.50	51.00
Average, ...				91.59	–	85.44	142.41	93.77	64.41

The gluten feed represented in these trials comprised three different lots of the same general type of chemical composition. It contained approximately 9 per cent. of water; and in dry matter the ash varied from .95 to 3.49 per cent., the protein from 25.47 to 28.29 per cent., the fiber from 7.30 to 8.70 per cent., the extract matter from 56.86 to 59.70 per cent., and the fat from 1.56 to 4.94 per cent. In general appearance the three samples resembled each other closely. The variations in percentage of ash and fat indicated some little difference in the manufacturing process, but not sufficient to warrant any noticeable variations in the digestibility of the several lots. In fact, the gluten feed used in Series XIX., Periods 2 and 14, and the same series, Period 15, were two different lots, and yet they resemble each other closely in digestibility.

Here follow the results of a number of early experiments. The process of manufacture was somewhat different, more of the germ being retained resulting in a higher fat percentage. The ash also was not much over 1 per cent. because the evaporated steep water was not added. Rather wide variations are noted as in the later experiments.

Summary of Earlier Work with Gluten Feed.

Digestion Coefficients.

Year.	Series.	Period.	Sheep.	Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
1893	-	2	II.	75.53	-	85.97	39.92	78.44	82.25
1893	-	2	IV.	80.44	-	83.94	46.28	84.37	80.58
1894	-	5	III.	89.35	-	88.69	94.69	88.93	92.74
1894	-	5	IV.	91.11	-	88.88	104.56	89.76	95.61
1896	-	-	-	87.00	-	86.00	77.00	90.00	81.00
1906	-	8	IV.	93.78	78.07	89.26	123.46	93.42	75.70
1906	-	8	V.	97.83	98.67	92.91	128.92	97.03	79.68
1909	XI.	7	IV.	92.25	85.05	90.02	107.23	92.30	76.29
1909	XI.	7	V.	99.24	93.69	92.22	153.69	97.98	77.29
1909	XII.	4	IV.	94.58	-	91.22	127.83	96.09	77.09
1909	XII.	4	V.	95.18	-	89.65	146.29	97.60	57.82
1909	XII.	14	II.	75.30	-	68.83	63.62	83.32	67.06
1909	XIV.	3	I.	99.18	77.54	87.31	134.91	103.30	97.79
1909	XIV.	3	II.	90.98	34.40	83.32	119.00	99.04	81.26
1909	XIV.	5	III.	85.81	51.15	81.84	81.74	94.04	79.46
1909	XIV.	5	IV.	101.55	64.83	88.58	147.10	108.24	84.21

Average Results.

Present experiments, . . .	91.59	-	85.44	142.41	93.77	64.41
Earlier experiments, . . .	90.57	-	86.79	106.01	93.36	80.36

Averages are not particularly satisfactory, especially when the figures from which they are made up vary widely among themselves. The foregoing averages show, however, the gluten feed to have a high digestibility.

A study of the numerous results brings out at least two striking facts. In the first place, in some experiments the coefficients are very much higher than in others. Thus, Series XX., Period 14, gave results very noticeably below the others.

It is the belief of the writer, however, that at least a part of the variation is due to the lessened activity of the digestive processes, even though such a condition may not be indicated by any outward signs. The changing from one ration to another may also change the intestinal flora.

In the second place, it is observed that in a number of instances the gluten feed appears to be over 100 per cent. digestible. It seems reasonable to assume that this is due to its favorable effect in increasing the digestibility of the hay; this condition was particularly pronounced in case of the fiber and to a lesser extent in the extract matter, and is in accord with the accepted teaching of the favorable influence of a protein concentrate on the fiber and extract matter of a basal ration having a wide nutritive ratio.

The digestibility of the protein varied in proportion to the digestibility of the extract matter, and is shown to be quite well utilized. The fat showed wide variations, due in part to the small amount present, and in part to other causes. The ash content of gluten feed is not large, and in most cases more ash was excreted from the total ration than was contained in the gluten feed fed, so that coefficients for this ingredient cannot be deduced.

Average Coefficients for All Results.

Different lots,	7
Number of single trials,	32
Dry matter,	91.08
Ash,	–
Protein,	86.12
Fiber,	124.21
Nitrogen-free extract,	93.57
Fat,	72.39

The average results for all samples indicate very clearly that gluten feed is a highly digestible nitrogenous concentrate, and that in all probability it exerts a favorable influence upon the digestibility of a basal ration having a wide nutritive ratio.

Summary of Coefficients for Diamond Gluten Meal.

SERIES.	Period.	Sheep.	Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
XIX.,	10	IV.	83	143	83.8	–	90.5	–
XIX.,	10	III.[1]	68	–	80.0	–	79.0	–
XIX.,	11	IV.	87	127	86.4	–	91.4	47.3
XXI.,	5	IV.	86	–	84.8	100	93.3	–
XXI.,	5	V.[1]	109	–	91.2	100	120.1	–
XXI.,	5	VI.	90	–	86.0	100	97.2	–
Average,[1]			86	–	85.0	100	93.0	–
Average of previous results (8),			87	–	88.0	–	88.0	93.0

[1] Results from Sheep III. and V. omitted from average.

A combination of 300 to 400 grams of hay, 125 grams of potato starch, and 100 to 125 grams of Diamond gluten meal were fed as a basal ration in order to study the digestibility of distillers' dried grains and corn bran. It seemed worth while in this connection to get at the digestibility of the Diamond gluten meal. In order to accomplish this the digestion coefficients found for the hay were applied to the hay consumed, and to the resulting product was added the amount of starch consumed, which was assumed to be entirely digested. The sum of the hay and starch digested was taken from the total amount digested, and the remainder represented the gluten meal digested. The coefficients used for the hay in case of Series XIX. represented an average of those secured by using the results from Sheep I., II., V. and VI., all of which agreed closely. Those used in Series XXI. were the average of those for Sheep VII., VIII., IX., X. and XI., as IV., V. and VI. had not been used in getting the digestibility of this lot of hay. The coefficients for the hay were as follows: —

SERIES.	Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
XIX., ...	59	28	52	62	62	47
XXI., ...	57	37	43	61	60	45

The nutritive ratio of the basal ration in Series XIX. averaged 1:6.5 and in Series XXI., 1:6.8.

In passing, attention is called to the fact that the ash, fiber and fat content of gluten meal are quite low, showing less than 2 per cent. of each on a dry-matter basis, and the coefficients secured were, as might be expected, of uncertain value, although it is reasonable to assume that these several constituents were quite fully digested.

The content of protein and extract matter, on the other hand, on the basis of dry matter, was 45 and 50 per cent., respectively, showing this feedstuff to be made of these two food groups in nearly equal proportions.

A study of the coefficients secured shows some wide variations. Sheep III., Series XIX., for some reason gave quite low results, and in Series XXI., Sheep V gave results considerably above the others. In making the average, therefore, it seemed wise to omit the coefficients obtained with these two sheep. The results show the gluten meal to have a high digestibility; in fact, it is believed that if a method sufficiently accurate were available it could be shown that the meal was practically all utilized.

The coefficients given for previous results represent eight single trials with four different lots, and were secured a number of years ago with gluten meal made by a little different process and averaging 40 per cent. protein and 54 per cent. extract matter in dry matter. The latter coefficients are in substantial accord with those recently secured.

Summary of Coefficients showing Effect of High-grade Wheat Gluten Flour upon Digestibility of Hay.

			Dry Matter.		Ash.		Protein.		Fiber.		Extract Matter.		Fat.	
Series.	Period.	Sheep.	With.	Without.	With.	Without.	With.	Without.	With.	Without.	With.	Without.	With.	Without.
XX.	10 and 12,	VII.	59	57	48	43	43	52	62	60	61	58	46	43
XX.	10 and 12,	VIII.	60	60	46	44	40	53	64	62	62	62	48	42
Average, . . .			59	58	47	43	41	52	63	61	62	60	47	42

The object of this trial was to observe the effect of a high-grade wheat gluten flour, composed largely of protein, upon the digestibility of the hay. In the hay experiment 600 grams were fed to each of two sheep, and in the experiment immediately following 40 grams of the gluten were added to the hay.

The hay contained in dry matter 6.66 per cent. ash, 8.36 protein, 32.08 fiber, 50.40 extract matter and 2.50 fat, and had a nutritive ratio of 1:12. The wheat gluten contained in dry matter .86 per cent. ash, 92.41 protein, .11 fiber, 6.23 extract matter and .39 fat, being nearly pure gluten meal, with traces of ash, fiber and fat, and a small amount of extract matter. The nutritive ratio of the hay-gluten mixture was 1:6. A study of the comparative coefficients of the hay when fed with and without the gluten — assuming the gluten to have been entirely digested — indicates that the latter improved the digestibility of the hay slightly, particularly the fiber, extract matter and fat. The protein, on the other hand, showed an apparent lessened digestibility, due perhaps to the fact that the protein of the gluten was not completely assimilated.

Applying the coefficients secured for the hay when fed by itself to the same hay fed in combination with wheat gluten, and subtracting the result from the total amount of hay plus gluten digested, we find that in case of one sheep 47.48 grams, and in case of the other, 33.95 grams, were digested against 36.36 grams fed. This indicates that in one case at least the gluten was not only fully digested but improved somewhat the digestibility of the hay.

Summary of Coefficients showing Effect of High-grade Wheat Gluten Flour upon Digestibility of Hay — Continued.

Series.	Period.	Sheep.	Dry Matter.		Ash.		Protein.		Fiber.		Extract Matter.		Fat.	
			With.	Without.	With.	Without.	With.	Without.	With.	Without.	With.	Without.	With.	Without.
XXI.	4[1]	VII.	55	55	36	28	45	42	58	59	58	59	44	42

[1] In case of hay alone, period 2.

This experiment was with a new lot of hay, testing in dry matter 6.59 per cent. ash, 7.59 per cent. protein, 32.67 per cent. fiber, 50.29 per cent. extract matter and 2.86 per cent. fat, and having a nutritive ratio of about 1:17, being very wide. The wheat gluten was the same as the lot previously fed, and the combination of 700 grams hay and 40 grams wheat gluten had a nutritive ratio of 1:5.7. In other words, the addition of 40 grams of gluten to 700 grams of hay produced a much narrower ration than if the hay had been fed by itself. A study of the coefficients shows no particular improvement in the digestibility of the hay as a result of adding the gluten, although such an improvement was anticipated.

Applying the coefficients secured for the hay when fed by itself to the same hay fed in combination with wheat gluten, and subtracting the result from the total amount of hay plus gluten digested, we have 38.58 grams of gluten digested as against 37.18 grams fed, showing the gluten to have been completely digested.

Summary of Coefficients showing Effect of High-grade Wheat Gluten Flour upon Digestibility of Hay — Concluded.

Series.	Period.	Sheep.	Dry Matter.		Ash.		Protein.		Fiber.		Extract Matter.		Fat.	
			With.	Without.	With.	Without.	With.	Without.	With.	Without.	With.	Without.	With.	Without.
XXI.	10[1]	IV.	61	57	46	37	47	43	66	61	64	60	38	45
XXI.	10[1]	VI.	61	57	44	37	46	43	67	61	63	60	39	45
Average, . . .			61	57	45	37	46	43	66	61	63	60	38	45
Average of all trials (5),			58	57	43	36	44	46	62	61	61	60	43	43

[1] In case of hay alone, periods 2 and 9.

The hay was the same as fed in the former trial; the gluten was a new lot, but did not vary in composition much from the previous sample used.

Unfortunately, Sheep IV. and VI. were not used in testing the digestibility of the hay, and the coefficients represent the average obtained by using Sheep VII., VIII., IX., X. and XI. It is evident in this trial that the gluten did improve the digestibility of the hay somewhat, particularly the fiber and extract matter.

Experiments by numerous investigators[1] have shown that when a ration containing considerable starch, and having a nutritive ratio of 1:12 or more, is fed to ruminants more or less of the starch is found in the feces, and if to this ration a protein concentrate is added the starch disappears, and the digestion coefficients, not only of the extract matter but also of the fiber, are improved. In our own case the addition of a small amount of a very rich protein food to hay improved the digestibility of the latter, but not in as marked a way as was expected.

Summary of Coefficients of Corn Bran.

SERIES.	Period.	Sheep.	Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
XIX., . . .	13	I.	90.08	210.29	49.64	99.91	90.24	74.88
XIX., . . .	13	II.	77.09	129.04	26.03	66.90	82.70	45.52
XXI., . . .	7	IV.	78.23	–	58.78	67.49	82.27	63.57
XXI., . . .	7	V.	81.89	–	22.56	96.10	86.33	65.16
XXI., . . .	7	VI.	75.66	–	61.83	49.20	84.21	78.51
Average, ...			80.59	–	43.77	75.92	85.15	65.53
Average of previous trials (2), .			71	–	55	65	75	83
Average of all previous trials (6),			71	–	60	71	80	80

The corn bran represents the hull or skin of the kernel, together with pieces of broken germ and more or less of the starchy portion which it is not possible to separate by mechanical means. It is often found in the markets of Massachusetts, and has been offered at a very reasonable price. In dry matter it contained 1.08 per cent. ash, 6.87 per cent. protein, 13.86 per cent. fiber, 76.33 per cent. extract matter and 1.86 per cent. fat. While low in ash and protein, its fiber content is not excessive, and it is quite rich in extract matter.

The hay-gluten meal-starch combination served as the basal ration. For some reason Sheep I., as indicated by the digestion coefficients, appeared to have utilized the bran quite fully. The results secured with the other sheep were as uniform as was to be expected, although Sheep II. and V. apparently made less use of the protein, while the latter sheep gave a high coefficient for the fiber.

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[1] See brief résumé in Die Ernährung d. landw. Nützthiere, by Kellner, sixth ed., pp. 53, 54.

The results are higher than those formerly secured by us, where the corn bran was fed together with hay, excepting those for protein and fat. It is evident that the fiber is quite well digested, much more so than that contained in wheat and oats. Comparing the corn bran with corn meal on the basis of net energy values it is found that if corn meal is placed at 100 corn bran equals 82.

Summary of Coefficients of Distillers' Grains.

SERIES.	Period.	Sheep.	Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
XIX., ...	12	IV.	65.79	-	79.47	16.21	70.55	93.22
XXI., ...	6	IV.	64.88	64.51	77.26	43.89	63.17	81.99
XXI., ...	6	V.	67.54	21.21	74.23	62.67	66.63	82.48
XXI., ...	6	VI.	67.94	23.21	77.24	54.98	69.16	77.10
Average, ...			66.54	36.31	77.05	44.44	67.38	83.70
Average of all previous trials for corn grains (17).			79	-	73	95	81	95
Average of all previous trials for rye grains (2).			58	-	59	-	67	84

The object of this experiment was to study particularly the digestibility of the fiber. For this purpose the grains were added to the hay-Diamond-gluten-meal-starch basal ration, which was quite low in that ingredient.

Distillers' grains represent the residues from the manufacture of distilled spirits. Those containing a high protein percentage are derived largely from corn. On the basis of 10 per cent. water the two samples contained 26.51 and 23.76 per cent. of protein, and may be considered of fair quality. The best grades usually contain 30 or more per cent. of protein. On the dry matter basis the average of the two samples contained 2.07 per cent. ash, 27.92 per cent. protein, 13.67 per cent. fiber, 46.69 per cent. extract matter and 9.65 per cent. fat.

In the present experiments variations are observed in the percentages of the several ingredients digested. It is rather surprising that such differences occur in the percentages of fiber digested. It is evident, in spite of the low fiber content of the basal ration, that the sheep did not utilize the fiber from the distillers' grains very well, which indicates that other grains than corn were used in the mash. Previous trials with corn grains showed higher coefficients for the total dry matter and for the extract matter and fat (see above), while the coefficients for the fiber were believed to have been too high. It seems probable that in the former trials, where the distillers' grains were fed with hay, the addition of the former increased the digestibility of the hay fiber. It is believed that the extent of the digestibility of distillers' grains will depend upon the kind of grains composing the mash. If much rye, barley and wheat are used the coefficients, especially those for fiber, will be lower than when corn is the predominating grain.

Summary of Coefficients of Feterita.

SERIES.	Period.	Sheep.	Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
XXI., . . .	12	V.	74.36	–	54.79	–	87.58	60.70
XXI., . . .	12	VI.	74.65	–	46.55	–	87.94	56.69
Average, ...			74.51	–	50.67	–	87.58	60.70
Texas Station,[1]			88.99	–	90.03	50.00	96.60	74.52
Corn for comparison (12), . . .			90	–	74	57	94	93

Feterita, or Sudan durra, is one of the grain sorghums, which include also Kafir, milo, durra and kaoliang. According to Morrison "it has slender stems carrying more leaves than milo but less than kafir, and erect heads bearing flattened seeds. Over much of the drier western portion of the grain sorghum belt these crops are more sure, and even on good soil return larger yields than corn." It has been stated that the average crop is 25 bushels per acre, with a maximum of 80 bushels (56 pounds) for feterita. The sample tested by us came from a carload received by an eastern grain dealer, and contained 10.41 per cent. water. Its dry matter consisted of 1.80 per cent. ash, 13.23 per cent. protein, 1.40 per cent. fiber, 80.23 per cent. extract matter and 3.34 per cent. fat. In chemical composition it resembles corn, being a little higher in protein and lower in fat. Hay and gluten feed served as a basal ration, and the feterita constituted 30 per cent. of the total ration. The results of the trial agree closely. It is surprising, however, that in total dry matter the coefficients fall so much below corn. Neither the protein nor the fat appear to be as well digested; the extract matter, however, approaches in digestibility that contained in corn. Corn contains substantially 85.7 pounds of digestible organic nutrients in 100, and on the basis of our results feterita contains 71.06 pounds, thus indicating that the latter has only 83 per cent. of the nutritive value of corn. There are no data from which to compute its net energy value. It is doubtful, however, if such data would show any wide variations from that secured as a result of digestion data. Further experiments with the feterita should be made, however, before drawing positive conclusions.[2]

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[1] See note 2.

[2] Since the above was written, Fraps of the Texas Station, Bul. No. 203, reports results with this grain showing higher digestion coefficients than those secured by ourselves. These coefficients are inserted above, together with our own.

Summary of Coefficients of Alfalfa.

SERIES.	Period.	Sheep.	Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
XXII., . . .	12	IV.	58.10	41.50	73.16	46.92	66.48	16.66
XXII., . . .	12	VI.	54.75	28.10	68.19	45.15	63.70	15.27
XXII., . . .	14	XII.	59.61	50.15	72.43	48.28	67.48	30.24
XXII., . . .	14	XIII.	58.50	50.68	73.32	45.23	66.81	32.29
Average, ...			57.74	42.61	71.78	46.40	66.12	23.62
Average all previous trials third cutting (6).			58	44	70	40	70	42
Average all previous trials (109), .			60	50	71	43	72	38

The alfalfa was quite free from foreign material. It represented the third cutting, and was grown in the State of New York. It averaged in dry matter 6.49 per cent. ash, 15.34 per cent. crude protein, 35.06 per cent. fiber, 41.13 per cent. extract matter and 1.98 per cent. crude fat. The results are satisfactory and are quite uniform with those previously secured. The fiber in alfalfa hay has relatively a low, and the protein a high, digestibility.

Roots and Vegetables.

It is generally assumed that roots and vegetables are quite fully digested by animals. Relatively few digestion trials have been made to determine the rate of digestibility and to note the effect, if any, of such materials upon the digestibility of feeds with which they are fed.

(*a*) *Cabbages.*

The whole cabbage, the head minus the outside leaves, and the leaves themselves were analyzed and digestion experiments carried out. The whole cabbage contained 88.27 per cent. water, and its dry matter consisted of 12.20 per cent. ash, 21.82 per cent. protein, 10.30 per cent. fiber, 53.76 per cent. extract matter and 1.92 per cent. fat.

The heads minus leaves contained 90.34 per cent. water, and the dry matter consisted of 8.22 per cent. ash, 17.98 per cent. protein, 9.84 per cent. fiber, 62.77 per cent. extract matter and 1.19 per cent. fat.

The outside leaves contained 80.95 per cent. water, and the dry matter consisted of 14.49 per cent. ash, 11.94 per cent. protein, 13.12 per cent. fiber, 58.04 per cent. extract matter and 2.41 per cent. fat. The exterior leaves contained about twice as much dry matter as the heads.

Cabbage is rich in protein, — in fact, considerably richer than the legumes, — on an equal moisture basis. It is rich also in ash, particularly the leaves, which may have been due in part to the adherence of soil particles. The percentages of fiber and fat are relatively low.

The cabbage was fed in combination with hay, and constituted 25 to 34 per cent. of the dry matter of the total rations, the latter having nutritive ratios of from 1:6.6 to 1:9.

Summary of Coefficients for Cabbage.

Whole Cabbage.

SERIES.	Period.	Sheep.	Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
XIX., . . .	7	I.	89.35	59.74	84.59	109.57	95.50	71.11
XIX., . . .	7	II.	86.49	54.19	87.67	72.48	96.22	68.33
Average, ...			87.92	56.97	86.13	91.03	95.86	69.72

Heads Minus Leaves.

SERIES.	Period.	Sheep.	Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
XVIII., . .	4	I.	99.84	80.55	84.92	124.79	103.16	53.26
XVIII., . .	4	II.	95.81	74.02	68.15	99.74	101.48	32.07
Average, ...			97.83	77.29	76.54	112.27	102.32	42.67

Leaves.

SERIES.	Period.	Sheep.	Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
XVIII., . .	5	I.	76.84	45.71	66.69	80.66	87.38	45.37
XVIII., . .	5	II.	71.39	44.23	60.90	75.79	81.30	29.40
Average, ...			74.12	44.97	63.80	78.23	84.34	37.39

The whole cabbage was quite well digested, with an average dry matter percentage in case of the two sheep of 88 per cent. The fiber averaged 91 per cent. digestible, showing in case at least of one of the sheep that it had improved the digestibility of the fiber in the hay. The extract matter also had a high digestibility (96 per cent.).

The heads proved rather more digestible than the whole cabbage, namely, 98 per cent., the protein 77 per cent., and both the fiber and extract matter over 100 per cent. It seems evident that the cabbage exercised a beneficial effect upon the hay with which it was fed.

The leaves did not prove as digestible as the center, although one notes that the dry matter averaged 74 per cent. digestible, the protein 64 per cent., the fiber 78 per cent. and the extract matter 84 per cent.

The whole cabbage, head minus leaves, and leaves would contain of digestible organic matter, on the basis of our data, in 2,000 pounds, the following: —

	Water (Per Cent.).	Protein (Pounds).	Fiber (Pounds).	Extract Matter (Pounds).	Fat (Pounds).	Total Fat x 2.2 (Pounds).	Nutritive Ratio.
Whole cabbage, . .	88.3	43.88	21.92	120.74	3.12	193.40	1:3.4
Head, ...	90.3	26.73	19.32	123.20	1.17	171.82	1:5.4
Leaves, ...	81.0	29.02	38.80	185.24	3.38	260.50	1:8.0

Because of the less moisture content the leaves show a larger amount of total organic nutrients than either the total cabbage or the interior. On the basis of 88.3 per cent. water, — that found in the whole cabbage, — the interior shows 207.2 and the leaves 160.4 pounds of digestible organic nutrients per ton. The whole cabbage, head and leaves, have the following relative values based upon digestible organic nutrients and natural moisture, or an equivalent moisture content of 88.3 per cent.: —

	Natural Moisture Basis.	Equal Moisture Basis.
Whole cabbage, ...	100	100
Head, ...	89	106
Leaves, ...	135	83

(*b*) *Carrots.*

Summary of Coefficients of Carrots.

Series.	Period.	Sheep.	Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
XIX., . . .	8	I.	89.10	33.48	52.03	131.89	95.66	79.63
XIX., . . .	8	II.	94.42	46.40	77.87	154.59	99.91	91.20
XX., . . .	8	IV.	74.42	50.22	77.71	40.19	85.71	-
XX., . . .	8	V.	87.81	64.89	85.35	101.96	93.22	25.87
XX., . . .	8	VI.	83.73	43.77	86.53	82.06	93.04	9.95
XX., . . .	9	IV.	100.70	74.24	87.61	89.58	105.20	162.90
XX., . . .	9	V.	115.80	91.86	106.00	148.71	113.51	204.84
XX., . . .	9	VI.	135.05	96.15	127.94	197.52	130.76	228.23
Average, ...			100.95	64.40	89.05	129.47	104.75	114.66

Two different lots of carrots were fed. They averaged 87.64 per cent. water, and in dry matter contained 9.56 per cent. ash, 10.11 per cent. protein, 8.53 per cent. fiber, 70.71 per cent. extract matter and 1.09 per cent. fat. They are low in protein, fiber and fat, and quite high in ash and in extract matter.

In the first and second experiments they were fed in combination with hay, and constituted about 30 per cent. of the total dry matter which had a nutritive ratio of 1:10 to 1:13.6. In the third experiment they were fed together with hay and gluten feed, and composed about 15 per cent. of the dry matter of the ration, which had a nutritive ratio of 1:7.6. Sheep IV. in Series XX., Period 8, showed such a low rate of digestibility that the results were not included in the average. With this exception the coefficients resulting from the hay and carrot combination agree reasonably well, and show 88.76 per cent. of the dry matter to have been digested. The protein and extract matter are also shown to have been quite well assimilated. The fat is so small in amount that the results have no particular meaning. In most cases a high fiber digestibility is observed; in fact, more was apparently digested than was consumed.

Where the carrots were fed with hay and gluten feed more of the dry matter was apparently digested than was fed. Thus one observes coefficients of 117 for the dry matter, 107 protein, 145 fiber and 116 extract matter. This, it is believed, was due to the coefficients used for the digestibility of the basal ration, composed of hay and gluten feed. These coefficients for some reason averaged only 62.43 for the dry matter, as against 68.4, the average for all of the other experiments. If, however, one uses the average figure of 68.4, the coefficients for the dry matter of the carrots vary from 67.4 to 101.66.

The coefficients as a whole indicate that carrots were quite fully utilized, and that they seemed to improve the digestibility of the basal ration with which they were fed. It is proposed to study this matter more fully.

(*c*) *Mangels.*

Summary of Coefficients of Mangels.

SERIES.	Period.	Sheep.	Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
XVIII., . .	3	V.	86.90	1.55	41.21	103.45	95.79	-
XVIII., . .	3	VI.	88.74	18.12	51.18	103.81	96.29	-
XVIII., . .	6	V.	85.43	41.31	48.36	89.58	93.40	-
XVIII., . .	6	VI.	87.20	52.36	63.00	85.31	93.67	-
Average, ...			87.07	30.58	50.94	95.54	94.76	-
Average of all previous trials (6),			84	-	59	78	94	-

Four single trials were carried out with one lot of mangels which contained 83.10 per cent. of water, — less than is found usually in this root. In the dry matter there was 6.10 per cent. ash, 5.84 per cent. protein, 6.38 per cent. fiber, 81.40 per cent. extract matter and .28 per cent. fat. The mangels were very low in protein, fiber and fat, and high in extract matter. They were fed in combination with hay only, and constituted from 40 to about 47 per cent. of the total dry matter of the combined ration, which had a nutritive ratio of 1:11 to 1:13. The coefficients are quite satisfactory, showing the dry matter to be 87, the protein 51 and the fiber and extract matter 95 per cent. digested. It is possible that the mangels improved the digestibility of the hay somewhat, but it is regretted that they were not fed also with a combination of hay and a protein concentrate in order to note if they would not have had a more pronounced effect.

(*d*) *Pumpkins.*

Summary of Coefficients of Entire Pumpkins.

SERIES.	Period.	Sheep.	Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
XIX., . . .	6	I.	75.87	64.82	70.50	59.74	81.54	96.29
XIX., . . .	6	II.	89.32	63.93	80.69	86.30	98.12	96.87
XX., . . .	2	I.	81.62	70.96	67.89	65.20	90.84	89.27
XX., . . .	2	II.	88.23	62.99	76.20	83.59	96.40	91.76
XX., . . .	3	I.	78.80	68.35	83.63	47.80	86.30	88.10
XX., . . .	3	II.	75.41	49.82	82.57	46.23	83.83	84.69
XX., . . .	4	I.	75.57	76.91	74.81	38.49	83.82	94.23
Average, ...			80.69	65.40	76.61	61.05	88.69	91.60

Pumpkins minus Seeds and Connecting Tissue.

XIX., . . .	4	I.	109.23	105.13	92.55	137.52	108.99	101.44
XIX., . . .	4	II.	93.84	59.48	93.96	95.16	102.44	83.81
Average, ...			101.54	82.31	93.26	116.34	105.72	92.63

Two lots of pumpkins, grown on two different farms in successive years, were used. One lot was tested whole, and also without the seeds and connecting tissue. The whole pumpkins averaged 87.53 per cent. water, and the dry matter contained 7.74 per cent. ash, 15.60 per cent. protein, 15 per cent. fiber, 49.37 per cent. extract matter and 12.29 per cent. fat. The edible portion contained 94.58 per cent. water, and its dry matter consisted of 8.81 per cent. ash, 13.74 per cent. protein, 17.33 per cent. fiber, 57.56 per cent. extract matter and 2.56 per cent. fat.

Wider variations occur in the digestibility of the different ingredients by the two sheep than are desirable. In case of Series XX., Periods 3 and 4, where the pumpkins were fed with a basal ration of hay and gluten feed, the coefficients for the fiber, extract matter and fat appear to be lower than when the basal ration consisted of hay only. One would expect contrary results, for the combination of hay and pumpkins had a nutritive ratio of 1:9 to 1:11, and the hay, gluten feed and pumpkins a ratio of approximately 1:7.5. The lower digestibility of the pumpkins in the hay-gluten-feed-pumpkin ration may have been caused by the extra amount of total dry matter fed (approximately 100 grams daily).

The coefficients for the pumpkins minus the seeds are considerably higher, and, so far as one is able to judge from the results, indicate that the pumpkins had a favorable effect upon the digestibility of the hay. When the entire fruit was fed no seeds or parts of seeds were found in the feces.

In general, it may be said that the entire pumpkins appear to be fairly well digested, but not quite as fully as are mangels, turnips and carrots. Their relative feeding values will depend considerably upon their content of dry matter. The large percentage of fat in the pumpkin tends to increase slightly its feeding value pound for pound over most of the root crops.

(*e*) *Turnips.*

Summary of Coefficients of Turnips.

Series.	Period.	Sheep.	Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
XVIII., . .	7	V.	88.78	55.34	70.15	87.75	95.48	56.90
XVIII., . .	7	VI.	89.17	51.38	81.08	75.55	96.64	75.86
Average, ...			88.98	53.36	75.62	81.65	96.06	66.38

One lot only of Swedish turnips was tested, which contained 86.21 per cent. water; the dry matter tested 7.33 per cent. ash, 9.58 per cent. protein, 10.99 per cent. fiber, 71.31 per cent. extract matter and .79 per cent. fat. They were rather richer in protein and fiber than mangels, and somewhat lower in carbohydrate matter. At the same time they may be regarded as carbohydrate in character. They were fed together with hay, and constituted 38 per cent. of the total ration, which had a nutritive ratio of 1:10.4. The results with the two sheep agree very closely, the sheep digesting 89 per cent. of the dry matter, 76 per cent. of the protein, 82 per cent. of the fiber and 96 per cent. of the starchy matter.

Comparative Summary of Coefficients for Roots and Vegetables.

	Water (Per Cent.).	DIGESTION COEFFICIENTS.						Digestible Organic Nutrients in 2,000 Pounds (Basis, 88 Per Cent. Water).
		Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.	
Whole cabbage,	88	88	57	86	91	96	70	193
Carrots, . .	88	101	64	89	129	105	115	233
Mangels, . .	83	87	31	51	96	95	–	196
Turnips, . .	86	89	53	76	82	96	66	204
Pumpkins, .	88	81	65	77	61	89	92	212

The total dry matter of the carrots appears to be more fully digestible and the dry matter of the pumpkin less digestible than that of the mangels, turnips and cabbage, the coefficients of which are quite uniform. The protein shows a high and uniform digestibility excepting that contained in the mangels. The fiber — excepting in the pumpkins, with its hard shell and seed covering — is shown to be quite well digested, as is also the extract matter. The fat is not of much consequence excepting in the pumpkin, which contains over 12 per cent. with a high digestion coefficient. On a uniform moisture basis of 88 per cent., the total digestible organic nutrients (including the fat multiplied by 2.2) do not vary widely from each other, with the exception of the carrots, which merit further study.

Summary of Coefficients of Vegetable Ivory Meal.

SERIES.	Period.	Sheep.	Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
XIX., ...	5	V.	84.43	44.35	–	55.01	93.27	–
XIX., ...	5	VI.	89.63	17.99	30.04	85.82	93.89	45.45
XX., ...	13	IV.	88.20	63.59	10.57	76.08	93.60	39.01
XX., ...	13	V.	98.96	94.01	34.61	120.48	99.99	60.28
XX., ...	13	VI.	101.71	44.24	41.70	129.22	102.28	31.91
XXI., ...	3	IV.	78.59	193.81	1.59	51.07	85.81	61.82
XXI., ...	3	V.	81.04	–	4.77	100.06	89.94	47.10
XXI., ...	3	VI.	84.03	90.95	6.04	66.45	91.98	58.70
Average, ...			88.33	78.42	18.47	85.52	93.84	49.18
Corn meal for comparison, . .			88	–	67	–	92	90

This material represents the sawdust or shavings from the vegetable ivory, or the corozo nut (*Phytelephas macrocarpa*). A complete report on its composition, digestibility and feeding value has been published elsewhere.[1] The details of the several digestion tests, however, were not given. The nut is used in the manufacture of buttons and similar materials; the residue is practically tasteless and of a tough, horny nature. Animals will not eat it when fed by itself, but usually consume it readily if mixed with one or more grains. It averaged in composition 10.76 per cent. water, and in dry matter 1.25 per cent. ash, 5.36 per cent. crude protein, 8.01 per cent. fiber, 84.37 per cent. extract matter and 1.01 per cent. fat. Its extract or carbohydrate matter is nearly all in the form of mannan, yielding mannose on hydrolysis.

The material in all cases was fed with 550 grams of hay and 150 grams of gluten feed as a basal ration, and constituted some 30 per cent. of the total ration.

A glance at the results show that the coefficients secured in Period 13 (hitherto unpublished) are noticeably above the others. This is believed to have been caused by the use of the coefficients secured for a basal ration of hay and gluten feed, which gave 62 as the digestibility of the dry matter as against 66 for the basal ration of hay and gluten feed employed in the other experiments. The average of the coefficients secured in Periods 5 and 3 (as published) gave 84 for the dry matter and 92 for the extract matter, and are believed to be more nearly correct.

The coefficients secured for the protein, fiber and fat are not surprising, in view of the smallness of the amounts present in the ivory meal in comparison with the total amounts of these ingredients consumed. The larger part of the ivory meal consists of carbohydrate matter, and it was quite well digested. How the mannan was decomposed in the digestive tract is not clear; it was found, however, to have largely disappeared in the feces. The ivory meal evidently is as fully digested as corn meal, and our published results of experiments with dairy animals demonstrate it to have considerable nutritive value.

Summary of Coefficients of Vinegar Grains.

SERIES.	Period.	Sheep.	Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
XXII., . . .	9	IX.	54.77	–	62.91	47.02	50.92	84.20
XXII., . . .	9	XI.	55.01	–	59.28	50.59	52.63	88.08
XXII., . . .	10	IV.	65.60	29.08	69.47	60.92	54.71	89.30
XXII., . . .	10	VI.	67.48	–	66.00	73.87	65.60	68.70
Average, ...			60.70	–	64.42	58.10	55.97	82.57
Dried brewers' grains for comparison (5).			61	–	81	49	57	89

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[1] Beals and Lindsey: Journal of Agricultural Research, Vol. VII., No. 7.

Vinegar grains were put out by the Fleischmann Company, Chicago, and represent the residue in the manufacture of yeast, or possibly of yeast and distilled liquors. They tested 7.63 per cent. water, and the dry matter contained 2.54 per cent. ash, 20.39 per cent. protein, 20.12 per cent. fiber, 50.33 per cent. extract matter and 6.62 per cent. fat. They were fed together with hay to four sheep. For some reason Sheep IX. and XI. did not digest them as well as did Sheep IV. and VI. The average results from the four sheep show that in total digestible matter, fiber and extract they compare well with dried brewers' grains, although the protein of the latter is more completely utilized. They are certainly an addition to our supply of protein concentrates, and can be used in the grain ration in a similar way to dried brewers' grains.

Summary of Coefficients of New Bedford Garbage Tankage.

SERIES.	Period.	Sheep.	Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
XXI., . . .	8	IV.[1]	54.22	63.14	33.90	–	68.04	–
XXI., . . .	8	V.	77.33	73.06	30.02	145.8	87.18	100.0
XXI., . . .	8	VI.	81.12	74.22	45.18	116.8	92.01	147.0
Average, ...			79.22	73.64	37.6	131.3	89.6	123.5

[1] Excluded from average.

This tankage represents the garbage collected in the city of New Bedford which was treated by the so-called Cobwell process. Briefly stated, the method of treatment consists in removing, so far as possible, from the material as received, all glass, tin cans, banana and orange peel, after which the residue is placed in large iron tanks and treated with benzine to remove the fat, which process also takes out the larger part of the water. It is then run over conveyors, and any other objectionable material is removed, after which it is ground.

The tankage contained 8.53 per cent. water, and in dry matter 15.72 per cent. ash, 22.02 per cent. protein, 9.67 per cent. fiber, 50.92 per cent. extract matter and 1.67 per cent. fat. It was in good mechanical condition, was fed with hay and gluten feed, and constituted about 18 per cent. of the ration, which had a nutritive ratio of 1:7.

Sheep IV. digested the tankage poorly, and it has seemed wise to exclude the coefficients from the average of those secured with the other two sheep.

The protein was not well digested, which indicated its inferiority as compared with material derived from slaughterhouses. This was confirmed by subjecting the tankage to the action of the alkaline permanganate method for determining nitrogen availability, and the securing of an availability coefficient of 44.66. Any nitrogenous matter testing below 50 by this method is considered of poor quality. The extract matter was quite well utilized, and likewise the small amount of fat. The fiber for some reason appeared to be completely digested, which is not probable.

The non-nitrogenous matter of the tankage was quite well utilized, but the protein is likely to prove inferior to the better grades of animal or vegetable nitrogenous concentrates.

Summary of Coefficients of New Bedford Pig Meal.

SERIES.	Period.	Sheep.	Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
XX., ...	11	IV.	68.99	48.02	67.35	18.45	84.02	133.77
XX., ...	11	VI.	69.29	40.96	71.39	26.18	83.40	142.88
Average, ...			69.14	44.49	69.37	22.32	83.71	138.33

This material according to the manufacturers was composed of 73 per cent. garbage tankage, 18 per cent. standard middlings, 7 per cent. prepared molasses feed and 2 per cent. linseed meal. It tested 8.80 per cent. water, and the dry material consisted of 19.65 per cent. ash, 23.59 per cent. protein, 9.15 per cent. fiber, 44.30 per cent. extract matter and 3.31 per cent. fat.

The sheep digested the entire mixture fairly well. Evidently the addition of the vegetable concentrates improved the digestibility of the total protein in the mixture. The fiber was poorly digested, but the extract matter and particularly the fat showed high coefficients.

It is quite reasonable to assume that garbage tankage is likely to vary considerably in quality.

Summary of Coefficients of Rowen.

SERIES.	Period.	Sheep.	Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
XXII., ...	15	XII.	60.81	34.23	60.39	68.12	63.37	30.01
XXII., ...	15	XIII.	61.16	35.76	60.27	68.08	63.57	34.53
Average, ...			60.99	34.40	60.33	68.10	63.47	32.27
Average previous trials (12), .			65	–	70	66	65	47

Rowen represents the second growth of meadows, and contains in addition to the grasses a considerable admixture of clover. The samples tested contained 9.13 per cent. of water, and in dry matter showed 7.19

per cent. ash, 8.14 per cent. protein, 49.02 per cent. extract matter, 2.39 per cent. fat and 33.26 per cent. fiber. While of satisfactory appearance it was inferior in composition to the average, which has been shown to test 11.4 per cent. protein and 24.1 per cent. fiber on a 14 per cent. water basis.

The digestion tests agree exceedingly well, but confirm the analysis, showing it to be rather less digestible than the average of previous trials.

Summary of Coefficients of Soy Bean Hay.

SERIES.	Period.	Sheep.	Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
XX., . . .	7	V.	52.27	11.63	70.90	49.36	54.78	53.91
XX., . . .	7	VI.	61.03	29.26	78.86	55.75	64.72	64.71
Average, ...			56.65	20.44	74.88	52.56	59.75	59.31
Average previous trials (4), .			60	–	73	57	64	44

The medium green soy beans were grown upon the station grounds, and were cut to put in the silo about the middle of September. They had not sufficiently matured to warrant their use as a seed crop. At the time of making the test the hay contained 11.73 per cent. of water, and, on a dry matter basis, 6.63 per cent. ash, 15.86 per cent. protein, 34.88 per cent. fiber, 40.56 per cent. extract matter and 2.07 per cent. fat. The tough, fibrous nature of the straw is in evidence in the high fiber content of the hay. Sheep V. was not able to digest the hay as well as Sheep VI. The results for the latter sheep agree fairly well with the average of the four other trials reported.

With the exception of the protein the ingredients in soy bean hay appear to be about equal in digestibility to those contained in average English hay. The higher digestibility of the protein is due to the presence of the beans. It is believed soy beans should be ensiled with corn rather than made into hay.

Summary of Coefficients of Stevens' "44" Dairy Ration.

SERIES.	Period.	Sheep.	Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
XXII., . . .	11	IV.	72.55	26.03	82.14	45.36	72.58	91.88
XXII., . . .	11	VI.	68.58	–	77.23	55.01	69.23	71.08
Average, ...			70.57	26.03	79.69	50.19	70.91	81.48

The Stevens' "44" Dairy Ration is one of the numerous proprietary dairy rations offered in Massachusetts markets. It is claimed to be a mixture of a great variety of the most desirable grains and by-products. It had 8.94 per cent. water, and in dry matter 4.17 per cent. ash, 26.95 per cent. protein, 12.88 per cent. fiber, 49.56 per cent. extract matter and 6.44 per cent. fat. Its high fiber content indicated the presence of some unsatisfactory material, and this was confirmed by the digestion test. The mixture proved to be fairly well digested, but not equal in total digestibility to mixtures of bran, cottonseed meal, gluten feed and corn or hominy meal. The fiber digestibility was considerably below that secured for hay, while the extract matter was below what one would expect in high-grade material. The protein, on the other hand, was quite well digested.

Digestibility of Sudan Grass.

This grass (*Andropogon sorghum* var.) was introduced into the United States in 1909, and has been tried at this station for a number of years. A full report on its merits will be given elsewhere. The green material contained from 76.5 to 80.42 per cent. of water when cut, and the hay averaged 14.47 per cent. of water. On the basis of dry matter the two samples of green material averaged 6.84 per cent. ash, 13 per cent. crude protein, 29.10 per cent. fiber, 47.13 per cent. extract matter and 3.93 per cent. fat. The hay averaged in dry matter 8.93 per cent. ash, 13.85 per cent. crude protein, 33.85 per cent. fiber, 41.80 per cent. extract matter and 1.53 per cent. fat. The green material was fed with English hay, and the ration had a nutritive ratio of 1:8.3. The Sudan hay in three out of four experiments was fed exclusively, and had a nutritive ratio of 1:5.7.

Summary of Coefficients of Sudan Grass.

Series.	Period.	Sheep.	Condition of Grass.	Dry Matter.	Ash.	Protein.	Fiber.	Extract Matter.	Fat.
XXII.	17	XII.	Green, first crop (heading).	77.23	86.93	79.61	85.45	69.63	86.59
XXII.	17	XIII.	Green, first crop (heading).	70.84	39.96	79.16	77.97	68.97	80.34
Average, ...				74.04	63.45	79.39	81.71	69.30	83.47
XXII.	1	IV.	Green, second crop,	65.41	37.97	62.86	69.40	67.70	64.69
XXII.	1	VI.	Green, second crop,	65.09	24.30	68.07	69.42	67.69	58.51
Average, ...				65.25	31.14	65.47	69.41	67.70	61.60
XXII.	3	IV	Dry, second crop, .	59.99	45.07	58.13	73.62	54.35	35.63
XXII.	3	VI.	Dry, second crop,	59.37	40.27	61.40	72.76	53.52	35.32
Average, ...				59.68	42.67	59.77	73.19	53.94	35.48

In Period 17, first crop, Sheep XII. digested the material rather better than Sheep XIII.

In Period 1 the green material, second crop, scarcely in head, was cut and fed in September. At the same time, some of it was made into hay and fed later. The total dry matter of the hay was over 4 per cent. less digestible than the same material fed green. Strange to say, the fiber showed a somewhat higher digestibility in the hay, while the extract matter was noticeably less digestible. As might have been expected, the fat (ether extract) showed a lower digestibility in the hay, due probably to the fact that the sheep were able more thoroughly to extract such substances out of the green plant. For some reason the sheep digested the second crop (green) less fully than they did the first. The latter was cut in 1917, and the former in September, 1916. Whether the lessened digestibility was due to the climatic variations prevailing in two different years, or because a second growth was actually not as digestible as the first, it is not possible to say. The average of the coefficients of the two lots of green Sudan grass follows, together with green barnyard millet, sorghum and corn for comparison.

Average Coefficients for Comparison.

	Number of Different Lots.	Single Trials.	Dry Matter.	Ash.	Protein.	Fiber.	Extract Matter.	Fat.
Sudan grass, ...	2	4	69.64	47.30	72.42	75.56	68.50	72.54
Barnyard millet (blossom),	3	6	70.00	56.00	65.00	73.00	71.00	58.00
Sorghum (past blossom), .	2	4	65.00	42.00	44.00	55.00	73.00	64.00
Corn fodder (dent) milk, .	7	17	70.00	39.00	62.00	64.00	77.00	76.00

The above comparison indicates that Sudan grass in digestibility is fully equal to other important green feeds.

Summary of Coefficients of Sudan Hay.

Series.	Period.	Sheep.	Character of Hay.	Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
XXII.	7	IX.	Before heading, first crop.	56.25	55.92	56.63	66.38	49.24	23.01
XXII.	7	XII.	Before heading, first crop.	55.14	51.42	55.22	66.42	48.74	10.38
XXII.	7	XIII.	Before heading, first crop.	57.15	56.93	57.83	66.82	50.51	19.62
Average, ...				56.18	54.76	56.56	66.54	49.50	17.67

Summary of Coefficients of Sudan Hay — Concluded.

Series.	Period.	Sheep.	Character of Hay.	Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
XXII.	6	IX.	Heading, first crop,	59.19	55.48	64.36	68.40	51.57	28.00
XXII.	4	IX.	Full blossom, first crop.	58.11	53.50	62.37	66.33	51.48	42.73
XXII.	4	XI.	Full blossom, first crop.	54.72	42.25	47.73	64.80	48.39	34.61
Average,				56.42	47.88	55.05	65.57	49.94	38.67
XXII.	3	IV.	Heading, second crop.	59.99	45.07	58.13	73.62	54.35	35.63
XXII.	3	VI.	Heading, second crop.	59.37	40.27	61.40	72.76	53.52	35.32
Average,				59.68	42.67	59.77	73.19	53.94	35.48
Average of all of above,				57.49	50.11	57.96	68.19	50.98	28.66

Results at Texas Experiment Station.

Series.	Period.	Sheep.	Character of Hay.	Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
–	39	1and2	Headed,	–	30.00	17.70	63.10	57.60	48.70
–	60	1and2	Full tassel,	–	23.50	58.30	58.60	41.80	45.20
–	62	1and2	Headed, blooming,	–	15.00	64.20	60.20	52.60	61.10
–	73	1and2	Late, mixed with crab grass.	–	32.20	57.30	62.80	59.60	61.10
Average,				–	24.80	49.40	61.20	52.90	54.00
Timothy hay, for comparison,				55	39.00	48.00	50.00	62.00	50.00
Barnyard millet, well headed,				57	63.00	64.00	62.00	52.00	46.00

In the above trials an effort was made to note the digestibility of Sudan grass cut at successive stages of growth. The results do not indicate any particular difference. The second cutting of hay appeared to be more digestible than the first. Whether this would hold true in all cases is of course not established. It is just the opposite from the results secured with the green Sudan grass. The probability is that much will depend upon the climatic conditions prevailing during growth. If the weather should be warm, with plenty of sunlight and moisture, it is possible that the second growth would fully equal and perhaps exceed the first growth in digestibility.

Results recently reported[1] from the Texas Experiment Station are somewhat below those secured by us, at least in case of the fiber. If one should eliminate the protein coefficient of Period 39 the remaining protein coefficients would be some two points above the Massachusetts figure.

In all of the trials one notes particularly the high digestibility of the fiber and the low coefficients secured for the extract matter and fat. This holds true also for the millet. The digestibility of Sudan grass is shown to be above that for timothy, and equal to barnyard millet. The difficulty in curing satisfactorily the coarse grasses, of which Sudan and millet are examples, render them less satisfactory for hay than that obtained from the finer grasses.

Digestibility of Sweet Clover.

Sweet clover (*Melilotus Alba*) is a biennial legume found quite widely distributed in southern Canada and the United States. The two samples used were grown on the experiment station grounds. The clover was fed green to the sheep, beginning about June 12 and ending June 26. At the close of the trials the clover was budding to early blossom, and the lower portion of the stalks was woody. The two samples averaged 84.50 per cent. of water, and in dry matter contained 7.08 per cent. ash, 19.40 per cent. protein, 30.29 per cent. fiber, 40.10 per cent. extract matter and 3.13 per cent. ash. The green clover was fed with hay, and the rations had an average nutritive ratio of 1:6.4.

Summary of Coefficients of Sweet Clover.

Series.	Period.	Sheep.	Condition of Clover.	Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
XXI.	14	IV.	Early blossom, .	64.80	47.93	75.29	60.56	64.07	49.91
XXI.	14	VI.	Early blossom, .	73.30	48.96	78.58	78.58	74.00	50.28
Average, ...				69.05	48.44	76.93	69.57	69.03	50.10
XXII.	16	IX.	Budding, . .	66.67	–	76.44	47.60	65.96	43.22
XXII.	16	XI.	Budding, . .	72.61	–	81.98	52.29	71.00	61.34
Average, ...				69.64	–	79.21	49.95	68.48	52.28
Average of both samples, ...				69.45	48.45	78.07	59.76	68.76	51.19
Alfalfa[2] for comparison, ...				61.00	–	74.00	42.00	72.00	38.00
Clover[2] for comparison, ...				66.00	–	67.00	53.00	78.00	65.00

[1] Bulletin No. 203, 1916.

[2] Henry and Morrison.

Sweet Clover Hay, Wyoming Station, Bulletin No. 78.

Series.	Period.	Sheep.	Condition of Clover.	Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
–	XIV.	1, 2, 3	Rank, late cut, .	60.88	65.79	75.46	33.63	72.04	30.94
Alfalfa[1] hay for comparison, ...				60.00	45.00	74.00	46.00	70.00	28.00
Clover[1] hay for comparison, ...				62.00	58.00	61.00	53.00	68.00	54.00

[1] Massachusetts Station.

Sheep IV. in Series XXI., and Sheep IX. in Series XXII. did not seem able to digest the clover as well as the other two sheep. The slight variation in the stage of growth of the clover appeared to be without influence on its digestibility. The young sheep IX. and XI. did not digest the fiber as well as did the old sheep IV. and VI. Sweet clover cut previous to blooming appeared to be quite well utilized, and showed rather higher coefficients than those for alfalfa or clover cut in bloom. The results of the Wyoming Station with sweet clover hay cut at an advanced stage of growth indicate that with the exception of the fiber it is as fully digestible as either alfalfa or clover hay.

TABLE VI. — COMPLETE SUMMARY OF THE AVERAGES OF ALL COEFFICIENTS, ARRANGED ALPHABETICALLY.

RATION.	Number of Single Trials.	Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
Alfalfa, ...	4	57.74	42.61	71.78	46.40	66.12	23.62
Cabbage (entire), ...	2	87.92	56.97	86.13	91.03	95.86	69.72
Cabbage (heads), ...	2	97.83	77.29	76.54	112.27	102.32	42.67
Cabbage (leaves), ...	2	74.12	44.97	63.80	78.23	84.34	37.39
Carrots, ...	8	100.95	64.40	89.05	129.47	104.75	114.66
Corn bran, ...	5	80.59	–	43.77	75.92	85.15	65.53
Distillers' grains, ...	4	66.54	36.31	77.05	44.44	67.38	83.70
English hay — basal, ...	23	59.47	36.31	49.78	64.10	62.35	46.34
English hay and gluten feed — basal,	14	66.59	33.25	66.39	67.75	69.91	51.89
English hay, potato starch and gluten meal (Diamond) — basal.	6	73.27	20.16	72.98	63.54	80.67	37.16
English hay and wheat gluten flour *(to note effect of the flour).*	5	58.00	43.00	44.00	62.00	61.00	43.00
Feterita, ...	2	74.51	–	50.67	–	87.76	58.70
Gluten feed, ...	16	91.59	152.58	85.44	142.41	93.77	64.41

TABLE VI. — COMPLETE SUMMARY OF THE AVERAGES OF ALL COEFFICIENTS, ARRANGED ALPHABETICALLY — *Concluded.*

RATION.	Number of Single Trials.	Dry Matter.	Ash.	Protein.	Fiber.	Nitrogen-free Extract.	Fat.
Gluten meal (Diamond),[1] . .	6	86.00	–	85.00	100.00	93.00	–
Mangels, ...	4	87.07	30.58	50.94	95.54	94.76	–
New Bedford garbage tankage, .	3	79.22	73.64	37.60	131.30	89.60	123.50
New Bedford pig meal, . . .	2	69.14	44.49	69.37	22.32	83.71	138.33
Pumpkins (entire), . . .	7	80.69	65.40	76.61	61.05	88.69	91.60
Pumpkins (seeds removed), . .	2	101.54	82.31	93.26	116.34	105.72	92.63
Rowen, ...	2	60.99	34.40	60.33	68.10	63.47	32.27
Soy bean hay, ...	2	56.65	20.44	74.88	52.56	59.75	59.31
Stevens' "44" Dairy Ration, .	2	70.57	26.03	79.69	50.19	70.91	81.48
Sudan grass (green), . . .	4	69.64	47.30	72.42	75.56	68.50	72.54
Sudan hay, ...	8	57.49	50.11	57.96	68.19	50.98	28.66
Sweet clover (green), . . .	4	69.45	48.45	78.07	57.76	68.76	51.19
Turnips, ...	2	88.98	53.36	75.62	81.65	96.06	66.38
Vegetable ivory meal, . . .	8	88.33	78.42	18.47	85.52	93.84	49.18
Vinegar grains, ...	4	60.70	–	64.42	58.10	55.97	82.57

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[1] See page 312.

BULLETIN No. 182 MARCH, 1918

MASSACHUSETTS
AGRICULTURAL EXPERIMENT STATION

SOY BEANS AS HUMAN FOOD

By ARAO ITANO

This publication has been prepared to furnish information
concerning the many forms in which soy beans
may be utilized

Requests for bulletins should be addressed to the
Agricultural Experiment Station
Amherst, Mass.

Massachusetts Agricultural Experiment Station.

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[1] On leave.

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Publication of this Document
approved by the
Supervisor of Administration.

BULLETIN No. 182.

DEPARTMENT OF MICROBIOLOGY.

SOY BEANS (*GLYCINE HISPIDA*) AS HUMAN FOOD.

BY ARAO ITANO.

INTRODUCTION.

For centuries the importance of soy beans as human food has been well known in oriental countries. Kellner,[1] Atwater [2] and others [3] bear testimony to this importance by their studies of the chemical composition, digestion and assimilation. Soy beans have furnished the chief source of protein to the people of Japan and China; they are in universal use, and have played the rôle of meat and milk for these nations. A lack of animals, the economic conditions and religious rites have all had their influence in making soy beans the leading protein food crop in this, one of the most densely populated sections of the globe. Although a great favorite and very important, the position of the white bean of the United States is scarcely comparable with the conspicuous place occupied by the soy bean in these eastern countries. It is the richest, cheapest and most productive of all legumes, and is prepared by nearly as many methods for human consumption as cow's milk.

At this particular time, when this country as well as others is searching out economical food and food production, it may be well to inquire into this article of food and its methods of preparation for humans, for it is doubtless one of the most promising in sight.

This being a popular presentation, the technical and theoretical discussions of the subject will be held for future treatment. Not only from the standpoint of food supply, but also from the standpoint of nitrogen supply to the soil and industrial uses, the soy bean occupies a very important place.

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[1] O. Kellner: U. S. Dept. Com., Bur. For. and Dom. Com., Special Agents Series, No. 84, Pt. I., 35.

[2] W. O. Atwater: Farmers' Bull. No. 142, 1902, U. S. Dept. of Agr.

[3] The Japanese investigations, Bulletins from College of Agriculture, Tokyo and Sapporo, Japan.

CHEMICAL COMPOSITION AND DIGESTIBILITY.

TABLE I. — *Chemical Composition of Dry, Ripened Soy Beans.*[1]

	SOY BEANS FROM —				
	China.	Hungary.	France.	United States of America (Goessmann).	Japan.
Crude protein,	38.69	31.21	34.92	33.36	42.05
Fat,	17.87	18.29	15.53	21.89	20.46
Crude fiber,	12.69	12.78	12.81	–	4.53
Starch,	3.49	3.51	3.53	–	–
Ash,	5.39	5.63	5.97	5.35	4.19
Other organic matter,	21.01	28.09	26.53	34.18	28.82

Table I. plainly indicates the very high percentage of protein, 31.21 to 42.05 per cent., and of fat, 15.53 to 21.89 per cent., which compares with beef (round steak), containing an average of 19 per cent. proteins and 12.8 per cent. fats.

While it is a well-established fact that these substances, namely, proteins and fats, are essential materials in animal nutrition, the results of recent investigations indicate that individual proteins differ in their digestibility and nutritive value, and that this difference is due to the particular amino acids which they yield upon hydrolysis. The interpretation, however, of such experimental results as have been thus far secured is somewhat confused. In case of the soy beans, the digestibility of the crude protein and fat is estimated at somewhere between 65 and 92 per cent., and 70 and 80 per cent., respectively, by the different investigators, such as Oshima,[2] Kellner [3] and others. Although these figures may not necessarily be indicative of actual food value, the relative merit of the soy bean as human food is very significant.

The author feels that there is still much to determine in the case of vegetable and animal proteins, and that we have not yet reached the stage in our knowledge where definite recommendations can be made. Prauswitz'[4] conception, one of many, may have some bearing in the case of this particular food, for the preparation of soy beans does seem to have a distinctive effect upon their digestive and assimilative values. It is possible that the fundamental differences in the nature of the nutrients, or proteins, may be disregarded. The long-continued, successful use of soy beans in oriental countries, over two thousand years, cannot be considered lightly in scientific interpretation.

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[1] M. Inouye: Bull. 2, 209, 1894–97, College of Agriculture, Tokyo, Japan.

[2] K. Oshima: Bull. 159, p. 191, 1905, U. S. Dept. of Agr., Office of Exp. Sta.

[3] O. Kellner: U. S. Dept. Com., Bur. For. and Dom. Com., Special Agents Series, No. 84, Pt. I., p. 35.

[4] Prauswitz: Ztschr. Biol., 35 (1897), p. 335.

HUMAN FOOD PREPARED FROM SOY BEANS.

The various food articles prepared from soy beans which are known to the author are named below (names in parentheses indicate the Japanese name): —

1. Soy bean milk (toniu).
    - Ordinary method employed in Japan.
    - Toniu from the soy bean meal.
    - Author's method.
    - Synthetic toniu.
    - Condensed.
    - Evaporated (yuba).
2. Soy bean curd (tofu).
    - Fresh tofu.
    - Frozen tofu (kori tofu).
    - Fried tofu (abura-age).
3. Baked beans.
4. Boiled beans.
5. Roasted beans.
6. Powdered beans.
    - Roasted.
    - Raw.
7. Green beans.
8. Soy bean pulp (kara).
9. Fermented boiled beans (natto).
10. Ripened vegetable cheese (miso).
11. Soy bean sauce (shoyu).
12. Vegetable butter and ice cream.
13. Oil (table use).
14. Lard (cooking).

SOY BEAN MILK (TONIU).

The author suggests a Japanese term, toniu, meaning milk from beans, to designate the liquid preparation from soy beans, the so-called "milk" from soy beans, to avoid confusion of terms. The toniu may be prepared by any one of the following processes, varying somewhat in quality and, accordingly, adaptation to use.

The Ordinary Method employed in Japan.

1. Soak the beans in water for twelve hours at room temperature, changing the water frequently.

2. Grind the beans to a fine smooth paste by means of a grinder, preferably a millstone, adding water to the ground mass from time to time, to the amount of three times the bulk of beans.

3. Boil the mass to foaming for one hour.

4. Strain through fine cheesecloth. The strained fluid should be white and opaque.

NOTE. — The toniu thus prepared resembles cow's milk. This is indicated in Table II. Upon standing, fat globules separate out on the surface. After standing several days souring takes place as in cow's milk. It can be used very satisfactorily for various family foods, as in the preparing of bread, cake, vegetable stews, soups, chocolate, candies, etc. It has a slight vegetable flavor which may be objectionable to some people for drinking purposes, although it is used to a considerable extent in oriental countries.

TABLE II. — *Composition of Soy Bean Milk compared with Cow's Milk (Per Cent.).*[1]

	Soy Bean Milk.	Cow's Milk.
Water,	92.53	86.08
Albuminoids,	3.02	4.00
Fat,	2.13	3.05
Fiber,	.03	–
Ash,	.41	.70
Non-nitrogenous extract including carbohydrates,	1.88	–
Milk sugar,	–	5.00

Table II. indicates the similarity in composition between toniu and cow's milk.

Toniu from the Soy Bean Meal.[2]

1. Add water to the amount of five times the bulk of the bean meal.
2. Let it stand for twelve hours at room temperature.
3. Boil it to foaming for one hour.
4. Strain through fine cheesecloth. The strained fluid should be white and opaque.

Author's Method.

1. Add water to the amount of five times the bulk of the bean meal.
2. Inoculate the content with *B. coli* and with *B. lactis ærogenes* as used in salt rising bread.
3. Let it stand for sixteen hours at room temperature.
4. Boil to foaming for one hour.
5. Filter through fine cheesecloth.
6. Add table salt to the amount of one-half teaspoonful per quart. The addition of 5 per cent. milk sugar (lactose) improves the taste, and may be desirable unless the milk is intended for diabetic patients.

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[1] M. Inouye: Bull. 2, 212, 1894–97, College of Agriculture, Tokyo, Japan.

[2] The soy bean meal may be obtained by grinding the beans in a wheat flour mill; a fine coffee mill works satisfactorily also. This preparation may be used in the same manner as the previous product.

NOTE. — The advantage of this method over the others may be summarized as follows: —

1. Elimination of disagreeable flavor.
2. Adjustment of taste.
3. Reducing the probability of flatulence in the alimentary canal.
4. Adaptability as a liquid food for diabetic patients.

The results of further investigation of the method and also of its nutritive value are withheld for the present.

Synthetic Toniu.

Toniu of very high quality, which resembles cow's milk very closely in composition, can be produced through both chemical and biological means; in fact, the author has been informed that this end has been accomplished in one of the London chemical laboratories. The author, however, doubts its practicability for domestic use.

Condensed Soy Bean Milk (*Condensed Toniu*).[1]

1. Add 4 grams of dipotassium phosphate and 600 grams of cane sugar to 4 liters of soy bean milk.
2. Concentrate the solution *in vacuo* to a very thick liquid.

NOTE. — It can be used like condensed cow's milk for the preparation of chocolate, etc. It gives an agreeable taste, but has a very feeble odor of raw beans.

Evaporated Soy Bean Milk (*Yuba*).

1. Boil the soy bean milk until a film is formed on the surface.
2. Collect the film and cut it in any shape desired.

NOTE. — The film consists of coagulated albuminoids and fat. It may be used as an article of food, cooked in soup, etc.

SOY BEAN CURD (TOFU).

TABLE III. — *Chemical Composition of Some Preparations* (*Per Cent.*).[2]

	Water.	Protein.	Fat.	Carbohydrates.	Ash.
Fresh tofu,	88.11	6.29	3.38	1.64	.58
Frozen tofu,	18.72	48.65	28.65	2.33	1.65
Fried tofu,	57.40	21.96	18.72	.57	1.35
Tofu cake (kara),	84.49	5.23	1.58	8.04	.66
Yuba,	18.31	49.65	18.00	11.82	2.22

Table III. indicates the chemical composition of various preparations from soy bean milk. The digestibility of the nutrients in tofu has been found to be as high as 95 per cent. for protein, 95 per cent. for fat, and 99 per cent. for carbohydrates.[1] Thus the composition and the digestibility of tofu establish it as a very nutritive food substance.

---

[1] T. Katayama: Bull. 7, 113, 1906–08, College of Agriculture, Tokyo, Japan.

[2] K. Oshima: Bull. 159, 28, 1905, U. S. Dept. of Agr., Office of Exp. Sta

The methods of preparation of these articles will be given in the following pages.

Fresh Curd (*Tofu*).

1. Prepare the soy bean milk either from whole beans or from bean meal as described previously.

2. Add 2 per cent. of any one of the following substances while it is hot, stirring constantly: —

(*a*) Mother liquid of sea salt.[2]
(*b*) Magnesium and calcium chloride solution.[3]
(*c*) Saturated solution of alum.[4]
(*d*) Vinegar.[5]

3. Filter off the liquid.

4. Press the precipitate in a wooden frame.

5. Let the pressed curd float in a large quantity of fresh cold water in order to free the coagulum from chemicals added.

NOTE. — In Japan tofu is prepared and sold in the market as baked goods are in this country. Its preparation may be too involved for the domestic kitchen. Among the coagulants the mother liquid of sea salt and the magnesium mixture are preferred to the others because the excess of these substances is almost completely removed by immersing in cold water.

Frozen Tofu (*Kori Tofu*).

1. Cut the fresh tofu into small pieces.

2. Subject the pieces to freezing.

3. Dry *in vacuo* after freezing.

NOTE. — The product thus prepared can be preserved for years and transported very easily. Freezing hastens the removal of water. The final product is porous and can be eaten in soups.

Fried Tofu (*Abura-age*).

1. Cut the frozen tofu into the desired size.

2. Fry it in rape-seed oil, sesame-seed oil, or in a large quantity of lard until the surface becomes brown.

NOTE. — It makes a very palatable, rich food, and may be eaten like fried egg or meat, or in soup.

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[1] When eaten with rice.

[2] This is commonly used.

[3] Mix the saturated solution of magnesium and calcium chloride in proportion of 4 : 1. (The author's recommendation.)

[4] Recommendation of the author.

[5] Recommendation of the author; ordinary table vinegar.

BAKED BEANS.

1. Soak the beans, suspended in a cloth bag, in a large quantity of hot water over night. (Soaking for twenty-four hours in cold water which is changed occasionally will give the same result.)

2. Change the water, when hot water is applied, in the morning and an hour or two before cooking.

3. Add 1 teaspoonful of soda per quart of beans and boil until the beans become soft.

4. Bake like other beans.

NOTE. — The characteristic strong flavor of the beans is removed by soaking before cooking; the addition of soda makes the beans soft. Cooking with salt pork, potatoes, onions, molasses and other substances makes the beans more palatable to some tastes.

BOILED BEANS.

Treat the beans as in the case of the baked beans, and boil them in a double boiler four to five hours until they become soft.

NOTE. — The addition of any one of the articles recommended for use with the baked beans may make the beans more agreeable to some people.

ROASTED BEANS.

1. Roasting can be done either in an oven or in an ordinary corn popper.

2. Roast until the skin of the bean is burst by popping.

NOTE. — The beans can be kept soft by immersing them in a syrup while they are hot. Thus very wholesome candy is prepared.

POWDERED BEANS.

Roasted.

1. Roast as in the roasted beans.

2. Let them stand until cool to harden them.

3. Grind them in a coffee mill or any other suitable grinder.

NOTE. — The powder can be used as salad dressing or cooked with cookies like peanuts and other nuts, or employed as a substitute for coffee.

Raw (*Soy Bean Meal*).

Grind the raw beans to a fine powder.

NOTE. — One part of bean meal mixed with 4 parts of wheat flour in bread makes a quite palatable bread, which is very nutritious; it is also used for biscuit, muffins, etc. Bread made of soy bean meal alone is recommended for diabetic patients, as it contains only very small amounts of starch, sugar and dextrin.[1]

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[1] A. L. Winton: Conn. State Exp. Sta. Rept., 30, 153-165, 1906.

GREEN BEANS.

1. Pick them when the beans are three-fourths to full grown.
2. Boil them in salt water.
3. Discard the pods.
4. Serve the beans with butter or milk.

NOTE. — The pods are tough and they can be removed easily on boiling.

SOY BEAN PULP (KARA).

1. This is the residue after the milk is extracted in the process of preparation of soy bean milk.
2. Cooked like any other vegetable with proper seasoning.

NOTE. — Makes a very rich dish; an addition of green onions, cabbage or parsnip may improve it.

FERMENTED BOILED BEANS (NATTO).

1. Boil beans for five hours.
2. Wrap inside of a straw bundle.
3. Smoke them in a closed cellar by building a wood fire and closing the door.
4. Let them ferment in a warm, moist atmosphere at 40° C. for twenty-four hours.

NOTE. — In making the bundle rice straw is preferred. This may not be suited to American palates on account of its peculiar flavor, which is due to the ripening protein. This recipe may also be undesirable on account of the difficulties involved in the process.

TABLE IV. — *Chemical Composition of Natto (Per Cent.).*[1]

Nitrogen proteids,	4.033
Nitrogen of amides,	1.892
Nitrogen of peptone,	1.617
Total nitrogen,	7.542

The relatively high percentage of total nitrogen may be due to the loss of carbon as carbon dioxide during the fermentation.

RIPENED VEGETABLE CHEESE [2] (MISO).

1. Preparation of "mother miso," or koji.[2]
2. Steam soy beans for twenty-four hours.
3. Rub into a thick, uniform paste.

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[1] K. Yabe: Bull. Vol. 2, 72, 1894–97, College of Agriculture, Tokyo, Japan.

[2] Koji used for manufacturing miso is similar to that used in making saké, — Japanese rice wine. It consists of barley or rice with a culture of certain forms of fungi, chiefly Aspergillus oryzæ. It contains diastatic, inverting and proteolytic ferments.

4. Add proper amount[1] of koji, salt and water.
5. Mix well and store in a vat at 15° to 20° C.
6. Let it ferment for a certain period of time according to the variety of miso.

Note. — Preparation of miso at home is not easily done because of the complexity of the technic, although it is very often practiced in Japan. Koji is sold in Japan on the market from special factories. It can be used very extensively for preparing soups, cooking vegetables, making sandwiches, etc. Different kinds of miso are produced through the use of different manipulations and components.

Table V. — *Composition of Red and White Miso (Per Cent.).*[2]

	Water.	Dry Matter.	Water, Soluble (Cold).	Protein.	Fat.	Fiber.	Starch, Dextrin, etc.	Glucose.	Alcohol.	Common Salt.	Total Ash.
White miso,	59.27	39.78	22.13	10.18	5.10	1.09	6.31	8.32	.95	5.99	7.70
Red miso,	50.16	48.66	32.28	12.48	6.46	2.31	2.72	10.40	1.18	10.84	12.40

Table V. indicates a high percentage of substance soluble in cold water. This fact makes it very convenient material to be used in soups. A trace of alcohol is present also.

Soy Bean Sauce (Shoyu).

1. One part each of beans, wheat and common salt and 2 parts of water are used.
2. Roast and pulverize wheat.
3. Steam and mash the beans as in case of miso. Cool to 40° C.
4. Add powdered wheat in the proportion of 70 parts of the caked beans to 30 parts of the wheat by weight. Mash and mix thoroughly.
5. Add spores of *Aspergillus oryzæ*, then mix. Spread upon wooden vessels or trays, about 3 liters per tray. The trays are stacked away in a cellar where the temperature is kept somewhat above 40° C. (After twenty to twenty-five hours, the mycelium of the fungus will be found; evolution of CO_2 and heat is observed as the fermentation proceeds; after about six days the growth of the fungus is completed, and an abundance of yellowish spores, "perithecia," is present. The temperature is kept approximately at 27° to 28° C.) Dry the material and grind. This is the shoyu-koji.
6. Heat the required amount of water and salt to 115° to 118° C. Cool to room temperature.

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[1] The amount to be added varies according to the kind of miso desired.

[2] K. Oshima: Loc. Cit. p. 30.

7. Mix shoyu-koji with the salt solution.

8. Allow the mixture to ferment in casks for one to two years with frequent stirring.

9. On the completion of fermentation, filter and press.

10. Allow filtrate to settle for two or three days.

11. Remove the clear supernatant liquid and heat it at 70° to 100° C. in a double boiler from two to three hours.

12. To improve the taste it is common to add a certain quantity of sugar or sweet saké during the heating process.

NOTE. — This sauce is mainly manufactured in zymo factories in Japan, for its preparation at home is too difficult. It is a thick, dark brown liquid and used extensively in Japan and China. It may be used in American kitchens for soups, gravies and vegetable stews, and makes a good substitute for Worcestershire sauce or any other table sauce. It has very slight food value, but its merit lies in its flavor, which seems to sharpen the appetite and accelerate the digestive functions.[1]

TABLE VI. — *Chemical Composition of Shoyu (Per Cent.)*.[2]

NUMBER OF SAMPLE.	Specific Gravity.	Water.	Protein.[3]	CARBOHYDRATE.		Free Acid, mostly Lactic.	Ash.	Common Salt.	Phosphoric Acid.
				Glucose.	Dextrin.				
1, . .	1.185	62.39	9.28	2.70	.69	1.18	18.48	16.03	.53
2, . .	1.190	62.82	9.53	3.33	.69	1.33	18.70	15.67	.51
3, . .	1.208	60.58	9.15	5.85	1.43	.92	20.14	17.47	.46

VEGETABLE BUTTER, ICE CREAM, OIL (TABLE USE) AND LARD (COOKING).

The manufacture of these articles from soy beans needs further investigation. To say anything further concerning their economical and industrial importance at the present time would be premature.

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[1] Pawlow: The Work of the Digestive Glands, London, 1902.

[2] K. Oshima: Bull. 159, 32, 1905, U. S. Dept. of Agr., Office of Exp. Sta.

[3] Consists of soluble albumin, peptone and further cleavage products. Eisei Shiken Jho: Bull. Imp. Sanit. Lab., Tokyo, No. 8, 35, 1897.

BULLETIN No. 183 MAY, 1918

MASSACHUSETTS
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By P. J. ANDERSON

This bulletin records results of investigations on a new and serious fungous disease of roses, and describes successful control methods

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PUBLICATION OF THIS DOCUMENT APPROVED BY THE SUPERVISOR OF ADMINISTRATION.

BULLETIN No. 183.

DEPARTMENT OF BOTANY.

ROSE CANKER AND ITS CONTROL.[1]

BY P. J. ANDERSON.

INTRODUCTION.

Rose canker is a serious disease of greenhouse roses which was first described in 1917. It has probably been long prevalent in America, but has escaped notice largely on account of its obscure symptoms and consequent difficulty of diagnosis. Its ravages were formerly assigned to other causes or left unexplained. Rose growers who first brought it to the attention of this station in November, 1916, stated that they had been suffering severe losses for at least four years. After conditions in the rose houses had been investigated, the situation was considered so serious that work was immediately begun to determine more of the nature of the disease, and especially to find a remedy for it. The investigation was started in co-operation with L. M. Massey, pathologist of the American Rose Society, who first observed the disease two months before this, and had already decided that its seriousness warranted a thorough investigation. Research at the Massachusetts station has been largely confined to determination of the best methods of controlling the disease and investigation of such facts in the life history of the causal fungus as have a direct bearing on control measures. Massey undertook investigation of other phases of the disease, and has recently published his results (1917). A successful method of control has been evolved and is presented in this bulletin, but it is hoped that, as a result of long-term experiments now in progress in commercial houses, this method will be improved and, possibly, other easier methods found. However, since this will require a number of years, the present method is published in order that rose growers who are troubled with the disease may have the benefit of all that we already know about canker and its control.

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[1] The writer is greatly indebted to Prof. A. Vincent Osmun, head of the department of botany at this station, for much valuable assistance, suggestions and criticism of the manuscript of this bulletin.

Only roses under glass are known to be affected. Some varieties, *e.g.*, Hoosier Beauty, are more susceptible than others, but there is yet no evidence that any are immune. Massey (1917) observed the disease on Hoosier Beauty, Ophelia, Hadley, Russell, Sunburst, American Beauty and many seedlings. It has been reported only from the northern and eastern United States, but closer observation will probably show that it has a much wider range.

SYMPTOMS.

The disease is most easily recognized by brown dead areas (cankers) in the bark of the stems. These are more frequent and larger at the crown than higher up, but any part of the stem or branches may be attacked. Crown cankers may be below the surface, just at the surface, or, more often, extending up the stem, sometimes several inches (Plate I., Fig. 1). They may be confined to one side or may girdle the stem. The young canker is blue-black or purplish in color and smooth, but as it becomes older the part above ground becomes reddish brown, dry, hard and cracked longitudinally. The margin is definite, and the dead area becomes sunken. Frequently the part of the stem immediately above the canker is swollen (Plate II.). When the subterranean part of the canker becomes old it is soaked and "punky," and the bark may be rubbed off between the thumb and forefinger, or it may rot away entirely (Plate I., Fig. 1). Sometimes a callus is formed around the edge of the canker.

Two types of cankers occur on the stem and branches higher up. The larger ones start from wounds, especially the stubs which are left after the blossoms are cut (Plate I., Fig. 2). Cankers from these stubs run back down the stems. The canker may stop at the first live branch below, but very commonly it continues to progress downward, and each successive branch dies as it is encircled by the descending canker. Cankers may also start from other wounds besides cut stubs. They are usually oval in outline and may be several inches long. The second type of aerial canker does not originate with wounds, but starts directly in the healthy green bark. First, small round purple areas appear, sometimes singly but more often in groups. As these increase in size the centers become light brown and the margins remain dark, giving a "bird's-eye" effect. When they occur in groups they coalesce and form large irregular dead areas in which, however, the individual cankers may still be distinguished for some time (Plate III., Fig. 2).

The depth of the canker varies, depending on such factors as the age of the part attacked, size of the infection court, environmental conditions and probably others. This is particularly a disease of the bark, and commonly the discolored area will be located outside the cambium entirely. But in more severe cankers it may extend to, or entirely through, the pith. If the shoot is young and has not yet hardened, the canker goes deeper and the entire shoot dies. This is frequently evidenced in the

PLATE I.

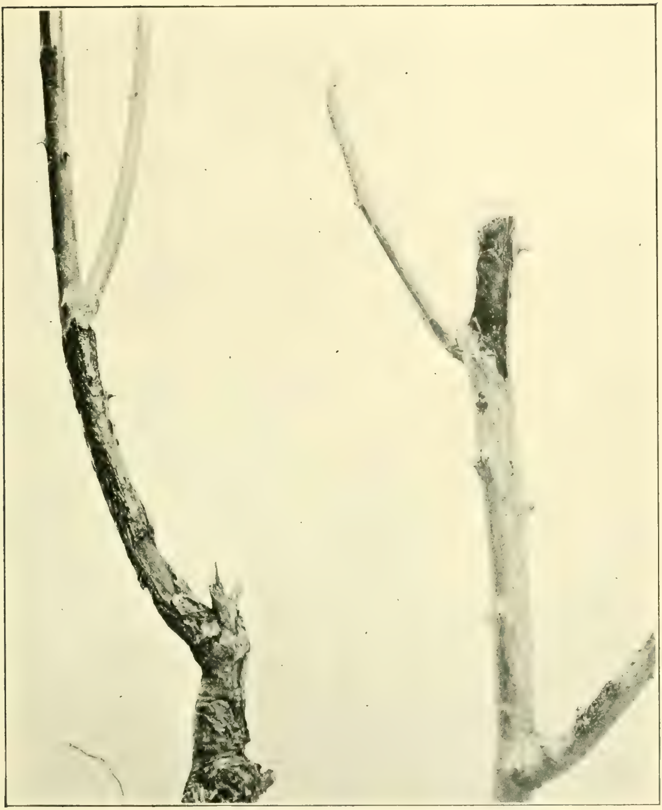
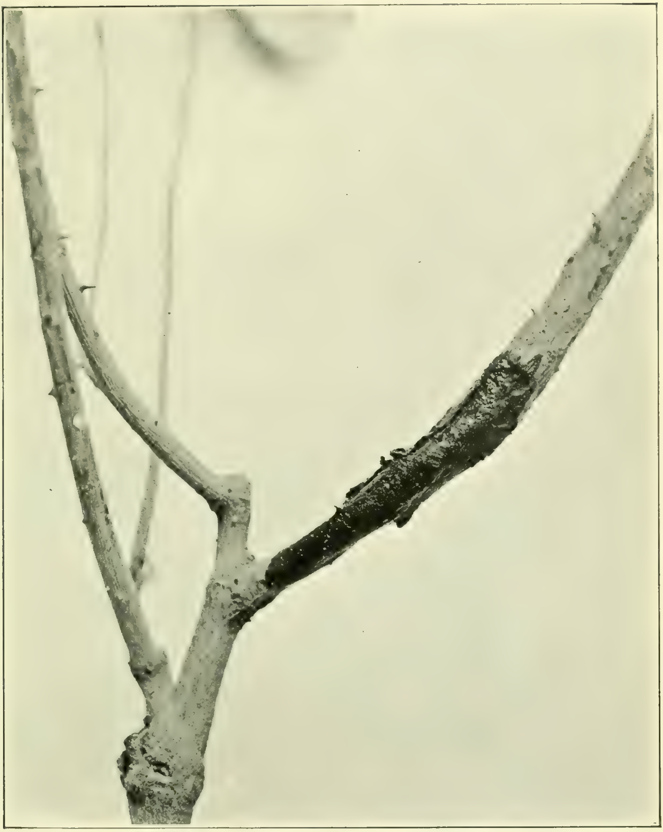


Fig. 1. — Old canker running up from the crown.

Fig. 2. — Canker running down from a cut stub.

PLATE II.



Canker on a lateral branch showing hypertrophy.

PLATE III.

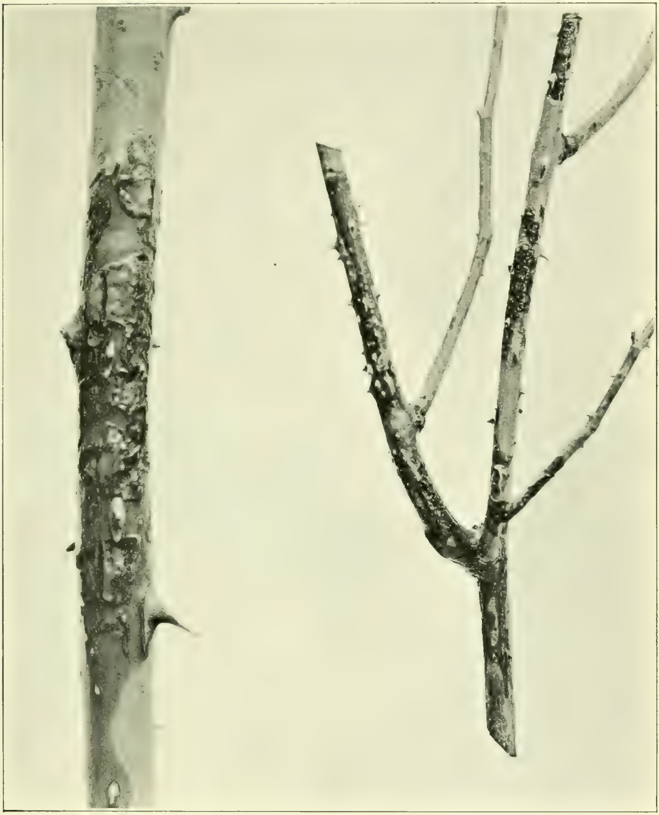


FIG. 1.—Canker resulting from coalescence of a number of small ones from stomatal infections.

FIG. 2.—Five cankers on a single stem.

sudden wilting and dying of shoots which have grown up rapidly from below the surface of the ground. Older shoots are rarely killed outright.

Only occasionally have we seen entire plants killed by this disease. One, several or all of the shoots of a plant may be attacked. Dead "brush" and dead small shoots are usually much in evidence in affected houses. The seriousness of the disease, however, lies not in the number of plants killed but in the fact that affected plants are small and weaker, resulting in diminished yields of inferior roses. The diseased plants cannot be forced, no matter how much fertilizer is applied and how well they are cultivated. New shoots do not grow from beneath the surface of the soil, but all come from the tops. These latter symptoms are the ones which the florist usually notices first, and, in fact, may be the only ones he notices.

Diagnosis of this disease is rendered difficult by two natural developments in the life of the rose plant which may easily be confused with disease: (1) Many varieties of roses naturally turn black at the crown very early; this, however, is a superficial blackening, and rarely runs up much above the surface of the ground. (2) The bark of all rose stems cracks with age, especially at the base, just as the bark of trees does. These two developments often resemble canker so closely that even one experienced in diagnosis may be misled.

DESCRIPTION OF THE CAUSAL FUNGUS.

Rose canker is produced by the parasitic growth of a fungus, *Cylindrocladium scoparium* Morg., within the tissues of the host (rose plant). Previous to 1917 this fungus had not been reported as a parasite. It was first found in Ohio by Morgan (1892) growing on an old pod of the honey locust (*Gleditsia triacanthus* L.). Seven years later it was reported again by Ellis and Everhart (1900) as growing on dead leaves of the papaw tree (*Asimina triloba* Dunal), and described as a new species, *Diplocladium cylindrosporum* E. and E.; but a study of the type materials of the two species by Massey showed them to be the same. As far as the literature shows, these are the only times that the organism had been observed up to 1916, and both times as a saprophyte.

The body of the fungus is composed of (1) mycelium, (2) sclerotia, (3) sporophores (conidiophores), and (4) spores (conidia). These four parts, or organs, of the fungus are here described separately.

MYCELIUM.

The mycelium is the part of the parasite which lives inside the tissues of the rose stem. It is composed of many microscopically slender, branching, tubular threads (hyphæ) which grow in every direction through the host cells for the purpose of securing nourishment from them for the fungus. Incidentally, in this process, the cells are killed and turn brown, thus producing the canker. The hyphæ are 4 to 6 u in diameter, and are divided by cross-walls (septa) into cells 5 to 20 times as long as their diameter. The manner of branching and septation is shown in Fig. 1. When the mycelium is young the walls are thin and not constricted, or, at most, only slightly constricted, at the septa. The contents consist of homogeneous protoplasm. Both the walls and contents are colorless, and when seen in mass, in pure culture, look like white cotton. But when the mycelium becomes older it becomes brown, the hyphæ are gnarled and twisted, deeply constricted at the septa, the cells short and oval or globose, giving one the impression of strings of beads (Fig. 2). The cells now contain large drops of reserve food, and the walls are thick. These cells are probably more resistant to adverse conditions, and serve to carry the fungus through unfavorable periods. They may be called chlamydospores. Their diameter is much greater than that of the ordinary hyphæ, as indicated by the figures.

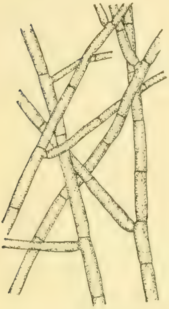


Fig. 1. — Young mycelium from culture.

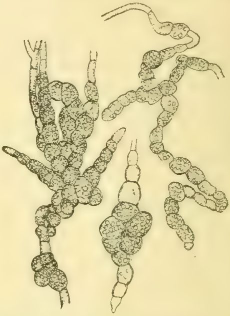


Fig. 2. — Old mycelium, showing chlamydospores.

SCLEROTIA.

Sometimes the surface of old cankers is dotted over with minute shining black pimples (Plate II.). They are usually not much larger than a pin point and never as large as a pin head. To the naked eye they look like pycnidia, but microscopic examination always proves them to be sterile balls of thick-walled pseudoparenchymatous fungous cells (typical sclerotia). They are directly under the epidermis, but this does not obscure their shining black prominence. In certain culture media they are produced in great abundance. The cells are much like the chlamydospores; in fact, the sclerotia seem to be only a further development of the chlamydospore-forming hyphæ, and all gradations between the two may be found. Their function is probably the same as that of the chlamydospores. A thin cross-section of one is shown in Fig. 3.

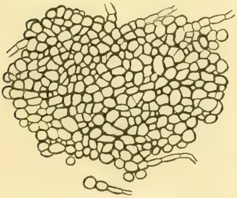


Fig. 3. — Thin section through a sclerotium.

CONIDIOPHORES.

The conidia, or ordinary spores, — as distinguished from the chlamydospores, — are borne on special upright branches, — conidiophores. These are produced in great abundance in artificial culture, but are rarely seen on the cankers. The writer has found them occasionally just at the surface of the ground on young shoots recently killed by the pathogene. But in badly infested rose beds which are kept wet they are produced in great abundance on dead shoots and parts of the rose plants which are cut off and left to decay on the ground under the bushes. To the naked eye the dead shoots seem to be dusted over in patches with a white powder. Under a strong hand lens — or better, a binocular microscope — each particle of this white powder is seen to be composed of a tuft of slender-stalked "brooms" with glistening white heads. One of these tufts is shown in Fig. 4. Each little broom is a conidiophore with its mass of conidia on the apex. The number of conidiophores in a tuft varies from 5 to 40, or more. No details, further than shown by Fig. 4, can be made out under the binoculars. Under the compound microscope, however, it is possible to determine accurately the structure of these little brooms. Examined in the dry condition they appear as in Fig. 5, where the conidia are cemented together into a solid head. But when mounted in water the cement which holds them together dissolves, many of them float away, and the head becomes loose as represented in Fig. 6. The main stem of the conidiophore may be unbranched up to just below the conidia, as represented by Fig. 5, or it may show one or more monopodial branches at

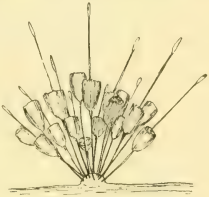


FIG. 4. — Tuft of conidiophores on a dead rose stem.

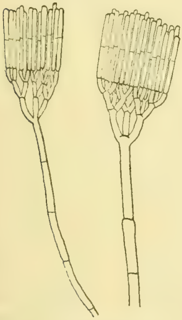


FIG. 5. —Conidiophores and conidia as seen in a dry condition.

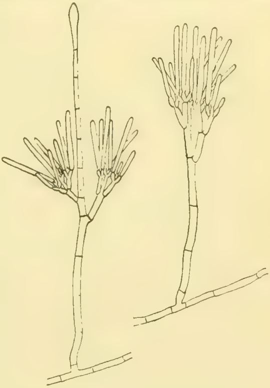


FIG. 6. — Conidiophores as seen when mounted in water, many of the conidia washed away.

various heights. The spores are frequently borne on lateral branches of this stem (Fig. 6), while the main stem is continued upward and terminates in an enlarged club. The ultimate branchlets, and one or two series below them, are usually in threes, as shown in Fig. 5, but twos are not uncommon. In regard to the dimensions of the conidiophore, Morgan (1892) writes: "the fertile hyphæ have a simple septate stem 5 to 7 μ in thickness, and are dissolved above into a level-topped cyme of branches; their height, exclusive of the spores which easily fall off, is 125 to 150 μ." Ellis and Everhart (1900) give the dimensions as 50–110 x 5–6 μ. In pure culture the writer has found them taller than the above measurements; an average of 50 conidiophores grown on potato agar gave 291 μ, and the diameter of the stalk, 6.6. μ.

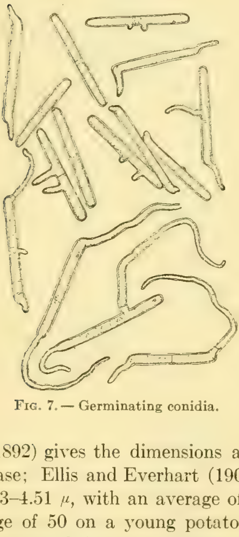


FIG. 7. — Germinating conidia.

CONIDIA.

The conidia are long, cylindrical, obtuse at each end, hyaline, divided into 2 cells by a septum at the center (Fig. 7). The contents are at first homogeneous, but later show vacuoles or oil drops (Fig. 8). Morgan (1892) gives the dimensions as 40–50 x 4 μ at the apex, and 3 μ at the base; Ellis and Everhart (1900), 40–50 x 4–5 μ; Massey (1917), 36–55 x 3.3–4.51 μ, with an average of 48.3 x 4.13 μ. The writer found the average of 50 on a young potato agar culture to be 48.8 x 5.1 μ; 50 on a two-months' culture, 39.2 x 4.03 μ; 50 produced on a pod of Gleditsia, 41 x 4.1 μ.

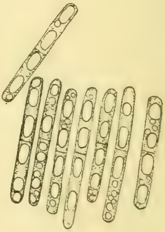


FIG. 8. — Old conidia.

LIFE HISTORY OF THE FUNGUS.

Before any measure of control could be intelligently attempted it was first necessary to become intimately acquainted with the life history of the causal organism (the pathogene). In the studies which are recorded below most attention was directed to those points which appeared to have a direct connection with control. Nevertheless, in order to become familiar with the entire life cycle, certain phases of development which have no obvious connection had to be investigated. For convenience in discussion, the life history is treated under three heads: —

1. Germination of the spores.
2. Parasitic life of the fungus (pathogenesis).
3. Saprophytic life of the fungus.

GERMINATION OF THE SPORES.

The life cycle begins with germination of the spores. The first essential condition for germination is the presence of water. Spores never germinate except when they are directly in water. A moist atmosphere is not sufficient. Germination takes place through the production of one or more tubes from each of the two cells of the spore. Usually the tubes do not start at the same time; one in each cell begins to grow, and this is later followed by another. Four germ tubes to each spore is the most frequent condition, but there may be more or fewer. The tubes may come out from any place on the surface of the spores, as illustrated in Fig. 7. They elongate very rapidly at laboratory temperatures, quickly develop septa, branch repeatedly and soon a mycelium is produced.

The brown thick-walled cells of the mycelium, which we have called chlamydospores, germinate by the production of slender hyaline germ tubes similar to those of the conidia and under the same conditions. Other detached cells of the mycelium also possess the power of germination. Especially is it common to see germ tubes arising from the cells of the main stem of the conidiophore when detached and kept in water. Such germ tubes usually arise from the end walls of the cells, and may grow directly through one or more old cells before emerging.

Temperature Relations.

The relation of temperature to germination of spores was studied carefully in the hope of evolving some method of control by keeping the rose houses at temperatures which are unfavorable for germination and thus retarding progress of the disease. The general effect of variation of temperature and the maximum, minimum and optimum temperature for germination were determined by the following method: —

Method. — Viable spores from a young, pure culture were transferred to a drop of water in the center of a glass slide. The slide was supported on two short glass rods in a Petri dish, used as a moist chamber. A few drops of water placed in the bottom of the dish kept the air humid and prevented drying out of the drop containing the spores. The Petri dish was then kept at the desired constant temperature in incubator, refrigerator or constant temperature room. Observations were taken and percentages of germination counted at regular intervals. No figures are based on the results from a single slide. Each result tabulated represents the average of several slides. Tests at high or low temperatures were controlled by duplicates at ordinary room temperatures.

The results of the tests are summarized in Table I.

TABLE I. — *Effect of Temperature Variation on Spore Germination.*

TEMPERATURE, CENTIGRADE (DEGREES).	Period before starting to germinate (Hours).	Percentage of Germination in 24 Hours.
5,	–	0
8-9,	24	1 (2 per cent. in 48 hours).
12,	5	95
15,	Not observed before 7 hours, when about 20 per cent. had started.	95
17,	4-5	95
20,	4½	95
22-23,	3-4	95
25-26,	2-3½	95
28,	Not observed before 6½ hours, when 95 per cent. had germinated.	95
30,	6½	95
31,	6½	70
33.5,	6½	21 (Erratic and abnormal).
36,	4	70
37.5,	–	0
40,	–	0

It is apparent from these tests that spores germinate at any temperature between 8° and 36° C. Between 12° and 30° the percentage of germination was almost total, ranging from 95 to 100 per cent. (all marked 95 per cent. in the table). Within these limits there was practically no variation of percentage due to temperature. In other words, if the optimum temperature is to be determined by percentage germination alone, it is very wide. Below 12° the percentage drops off rapidly until at 8° to 9° we get but 1 per cent. in twenty-four hours. Germination ceases altogether below this. Between the temperatures of 31° and 36° it is difficult to express the effects of temperature in percentages. Not only is germination erratic, varying greatly in slides apparently treated alike, but it may also be so abnormal that it is difficult to determine just what constitutes germination. The spores assume peculiar shapes by the development of knobs or, more commonly, globose swellings twice the diameter of the spores. These vary in number and location, but most frequently they are on the ends of the spores. Very slender unbranched germ tubes may grow for a time from these. The percentage of spores affected does not gradually diminish to form a regular curve. Thus, in one test at 36°, 70 per cent. were affected in this way. But at 37.5° there was no germination or change in the spores which could be detected with the microscope. The effect of temperature variation is more apparent in the *time required* for germination to begin than in the final *percentage* of germination. In this respect there is a rather regular curve. The optimum is at about 25°, where germination begins in two to three and one-half hours. At 12° it required five hours, and at 8° no germination was apparent until after twenty-four hours. The fact that spores do not germinate at a certain temperature does not mean that they are dead. Spores kept for two days at 5° showed not the least indication of germination, but when brought back to ordinary room temperatures they quickly germinated to over 95 per cent. Experiments to be described later show that spores may be kept for long periods at temperatures both lower and higher than indicated in this table and still retain their viability.

Apparently there is little opportunity for retarding the progress of the disease by maintaining temperatures in the house unfavorable to the fungus, because the optimum temperature for spore germination is approximately the same as the optimum for growing roses. The latitude of the germination optimum is also unfavorable to such a method of control.

Effect of freezing the Spores.

It is a well-known fact that the spores — especially the conidia — of many fungi are quickly killed by freezing, and this weakness may be utilized in checking disease. The purpose of the present investigation was to determine whether the spores of Cylindrocladium can be killed by freezing, and if so, how much exposure is required. Two methods were used.

First Method. — Petri dishes containing young cultures with abundance of spores were exposed to out-of-door temperatures of —3° to —10°C. Checks were first made at room temperatures to test the viability of the spores. Spores were removed from the frozen plates at regular intervals and put to germinate in moist chambers at ordinary room temperatures, as described above in spore germination tests. By this method the spores were dry when frozen.

After about two hours the percentage of germination began to decline; in eight hours it had fallen to 10 per cent.; in twelve hours, to less than 1 per cent.; and at the end of fourteen hours there was no germination whatever. All checks germinated 95 per cent.

Second Method. — Spores were transferred from plates along with a portion of the agar to drops of water on slides. All was macerated until the spores were well distributed through the water. They were immediately put outside to freeze and one slide brought into the laboratory at the end of each hour and tested for germination.

The results were very similar to those obtained by the first method. Freezing for one hour seemed not to affect them at all; in two hours the percentage dropped to from 75 to 80 per cent.; in three hours, to 30 per cent.; in six and one half hours, to 25 per cent.; in ten hours, to 1 per cent. From 1 to 2 per cent. germinated even after exposures of twenty-four hours, but these were spores in the center of the drop of water, or directly in the agar, which seemed to give them some protection. There was no germination whatever after thirty-six hours.

The first method more nearly approximates natural conditions, but under any conditions we may safely draw the conclusion from these experiments that all spores are killed by freezing during thirty-six hours.

Thermal Death Point of Spores.

Investigation of this point was undertaken with a view to the possibility of sterilization by heat. Thermal death point is defined as the lowest temperature at which an organism is killed by an exposure for ten minutes. Since this point might be different for spores than for mycelium, each was tried separately.

Method. — Spores from a young culture immersed in a drop of water were placed in a thin pipette tube, sealed at one end and covered with a rubber cap at the other. The tubes were then dropped into vessels of water kept at the desired temperature. Each vessel was supplied with a thermometer, and could be heated by a Bunsen burner when necessary. After ten minutes the tubes were removed, the sealed end filed off, and the spores forced out through it on to a glass slide by pressing the rubber cap at the other end. The slides were then put in moist chambers as previously described in germination tests. These were kept at ordinary laboratory temperatures. Temperatures at intervals of 1°, from 40° to 55°, were tried. All tests were made in duplicate several times.

Up to and including 46° the spores did not seem to be affected by ten-minute exposures. Above this the percentage remaining alive declined very rapidly to the absolute thermal death point of 49°. At this temperature none ever germinated.

It was also found that spores can be killed at lower temperatures than 49° by exposing them for longer periods. In some previous experiments it had been determined that they are killed by an exposure to 37.5° for twenty-four hours. At 42° they are killed in two hours. To determine the effect of varying the period of exposure at a given temperature, 40° was selected as a standard, and spores exposed (in drops of water on slides in Petri dishes) during periods differing by intervals of one hour. They were then brought back to room temperature and tested as above. The results of this series are given in Table II.

TABLE II. — *Germination of Spores after Exposure to a Temperature of 40° C.*

PERIOD OF EXPOSURE (HOURS).	Time required after Removal to Room Temperature before beginning to germinate.	Percentage of Germination after 24 Hours at Room Temperature (20–24° C).
1,	95 per cent. in 3½ hours. Not observed sooner.	Over 95
2,	2½ hours. Just starting.	Over 95
3,	3 hours. Just starting.	Over 95
4,	60 per cent. after 5 hours.	Over 95
5.	At least longer than 4 hours.	50
5½,	1 per cent. in 7 hours.	3
6½,	At least longer than 6 hours.	0.5
7½,	– –	0
9, 12, 14, 18, 20,	– –	0

It will be noticed that the longer the period of exposure, the longer the time required for germination after being removed to room temperature. There was no decrease in the percentage of germination until after four hours. From this point it dropped rapidly to less than 1 per cent. in six and one-half hours, and no germination whatever after seven and one-half hours.

Effect of Desiccation on the Spores.

The length of time during which spores are able to live in a dry condition may have an important bearing on dissemination of a fungus and spread of a disease. Neither the thinness of the walls nor character of the spore contents of Cylindrocladium would lead one to expect great longevity. The following method was used to determine longevity at ordinary room humidity: —

Method. — The lids of Petri dishes, containing pure cultures of Cylindrocladium with abundance of conidia, were lifted enough to allow the thin film of agar to become hard and dry within a day or two. At intervals of one day spores were transferred from these dishes to drops of water on slides in Petri dishes, as previously described for other germination tests. The percentages of germination were determined after the spores were kept in moist chambers for twenty-four hours. All checks — made from the cultures before tilting the lids — germinated to over 95 per cent. Several hundred spores were transferred for each test. Three different Petri dish cultures were used at different times.

In every trial the percentage of germination began to decline after twenty-four hours. In two days it had dropped to 25 per cent.; in five days, to 10 per cent. After ten days not more than 1 per cent. germinated, and in no case was any germination observed after drying for fifteen days.

The longevity of conidia, then, appears to be very limited when kept in a dry condition. When the atmosphere is kept very humid they live longer, at least several weeks, but no careful investigation has been undertaken to determine just how long with each degree of humidity. If water stands on them, even in the culture dish, they germinate and then quickly die if dried out at once.

PARASITIC LIFE OF THE FUNGUS.

Pathogenicity.

In order to prove that an organism is the causal factor of a certain disease there are four requirements — called the four rules of proof — which pathologists all agree must be fulfilled. These are: (1) find the organism constantly associated with the disease; (2) isolate the organism, grow and study it in pure cultures; (3) produce the disease again by inoculation from these pure cultures; (4) reisolate the organism and prove by culture its identity with the organism which was first found. These four rules were complied with by Massey (1917), and the pathogenicity of *Cylindrocladium scoparium* established. The present writer has also given the four rules repeated test, and obtained results similar to those of Massey. These experiments are not described in detail here, but only certain notes on each of the four steps recorded.

1. Constant association of the pathogene with the canker is not so easy to establish as in most fungous diseases because the fungus can rarely be seen with the naked eye on cankers in rose houses. Nevertheless, the writer has occasionally been able to find a white band of conidia around cankers on young shoots just at the surface of the ground. Almost always when a canker is kept in a moist chamber for twenty-four hours or longer the mycelium grows out as long, straight, white hyphæ, which can readily be recognized as peculiar to Cylindrocladium by one who has become acquainted with the appearance of this fungus. Also, after a few days in the moist chamber, conidia usually begin to develop on the surface. The presence of the pathogene in old cankers is also often betrayed by sclerotia, — small, flat, shining black specks just under the epidermis. Yet the writer has often found cankers in which the organism could not be determined in any of the above ways. There seems to be only one absolutely sure way of determining association of the pathogene in all cases, and that is by making isolations, which is really a part of the second rule of proof.

2. The following has been found the most satisfactory method of isolation: —

Method. — The surface of the canker is first sponged with mercuric chloride 1–1,000. Scalpels and steel needles are kept in a jar of 95 per cent. alcohol. The epidermis, or at least a thin outer layer of the canker, is then peeled off with a scalpel from which the alcohol has been burned over a Bunsen. Another scalpel sterilized in the same way is used to cut out a portion of the peeled canker. It is then removed with a flamed needle to a flask of sterile water, washed, and transferred to a potato agar slant — or sometimes poured plates are used. One or two drops of lactic acid are added to the tube of agar when slanted. The acid not only prevents growth of bacteria, but also seems to make the medium more favorable for the growth of Cylindrocladium. Occasionally other agars, such as corn meal, oat, lima bean, Czapek's and Cook's No. 2, have been successfully used, and there is no objection to them. The almost constant use of potato agar in the present investigation is due more to habit and convenience than to any advantage over other media. In the case of small initial cankers the epidermis was not peeled off. The mycelium grows up into the air and into the agar very quickly, and after some experience one is able with the naked eye to distinguish within twenty-four hours the growth of Cylindrocladium from that of other fungi he is apt to meet with on roses. But if there is any doubt, he has but to wait another day or two, and spores are produced by which this fungus can be absolutely identified.

Other methods of isolation besides tissue transfers have been successfully used. Where spores are present, or where they have been developed in moist chambers, cultures are very easily made by touching them with the tip of a sterile platinum needle, — first thrusting the needle into the agar so that more spores will adhere, — and then transferring to agar slants. When the sclerotia were first discovered on the cankers there was some question as to their connection with Cylindrocladium. Some of them were picked out under the binoculars with a sterile needle, freed from all clinging rose tissue, washed in sterile water, and transferred to agar plates. In this way, also, pure cultures were obtained.

By the first method described, the organism has been isolated in pure culture from hundreds of typical cankers. In order to determine the very youngest stages, a number of stems showing the little round lesions (described under "Symptoms"), from the size of a pin point to several millimeters in diameter, were brought into the laboratory, washed merely with sterile water, and transfers made as above. Pure cultures were obtained from even the smallest of them.

The relation of the pathogene to dead stubs was also determined in this way. After the flower is cut, one or more shoots quickly grow out from below the cut end of the stem. The topmost one, however, is usually some distance below the cut surface, and a useless stub is left from 1 inch to 3 or 4 inches long. This stub usually dies slowly from the apex back to the first branch, where it is apt to stop. When the canker disease is prevalent in the house, however, the dying frequently does not stop at the first shoot but continues down the stem, and the shoots die as they are encircled by the descending dead area. Frequently the fruiting bodies of various species of fungi, such as Pestalozzia, Phoma, etc., can be found on these stubs, but in other cases no spores could be found. A large number of them were collected from a house known to be infested, and transfers made. Cylindrocladium was obtained from over half of them. After they were found to be infested in some cases, more attention was directed to them and the sclerotia frequently observed. It was from these sclerotia that the pure cultures mentioned above were obtained.

Study of the fungus in pure culture will be described later.

3. Plants were inoculated in four different ways: —

Methods of Inoculation. — (*a*) Stems wounded, inoculated with agar in which the fungus was growing, kept moist several days with moist cotton. (*b*) Same as (*a*), but the plants not wounded. (*c*) Wounded, spores sprayed over the plants with an atomizer, and kept for several days under a bell jar. (*d*) Same as (*c*), but plants not wounded. All these methods were controlled by checks treated in the same way except for applying the fungus.

Typical cankers were produced by all four methods of inoculation. The shortest incubation period — time between inoculation and first appearance of symptoms — was four days on the wounded plants and five days on the unwounded ones. The rate of development of the canker after it first appears varies greatly. On some plants which were first wounded and kept under bell jars the cankers were over a centimeter across in two weeks, but if the bell jars were removed and the humidity of the air diminished, the cankers grew very slowly. Small aerial cankers usually soon stop growing altogether unless several of them occur close together, or unless they are kept very moist. Crown cankers grow more rapidly than cankers higher up, but their rate of growth becomes decidedly slower as they advance above the surface of the soil.

4. Reisolations were very readily made from a number of the cankers produced by artificial inoculation. The fungus was obtained in pure culture, and easily identified by its cultural and morphological characters as *Cylindrocladium scoparium.*

Infection Court.

The artificial inoculations described above indicate that a wound is not necessary for infection. All observations indicate, however, that a wound is a very favorable infection court. A great many of the basal cankers start from the union of stock and scion; aerial cankers from the cut surfaces of stubs and from various bruises made by tools, etc. Even where no wound appeared, it seemed possible that there might be small wounds not readily visible to the naked eye. In order to determine whether such was the case, and if not, to determine whether any natural openings in the epidermis serve as infection courts, artificial inoculations were made by spraying spores with an atomizer on what, as far as could be seen with the naked eye, seemed to be perfectly healthy stems. As soon as cankers began to appear they were cut out, fixed, imbedded in paraffin, cut into serial sections and stained. Twenty-four cankers varying from the size of a pin point to 2 millimeters in diameter were used and cut serially to a thickness of 8 μ. In no case was any wound through the epidermis discovered. But in every case a stomate was located directly at or very near the center of the canker. In the larger cankers there were several stomates, and it was not always possible to determine the point of entry. In the smaller ones, however, only one was present, and it was always approximately at the center. A number of infections were also discovered which were so small that they had not been seen when the material was fixed. In some cases the affected cells extended no farther than 5 or 6 rows below the stomate.

There does not seem to be any reasonable doubt that the stomates serve as infection courts, and that the little round lesions on the smooth stems are largely the result of these stomatal infections.

The Mycelium in the Host Tissues.

In order to follow the course of the mycelium after it has entered the rose stem, and to determine its effect on the host tissues, cankers in every stage of development, from that where they are not yet visible to the naked eye up to the old, fully developed lesion, were sectioned, stained and studied.

Method. — The mycelium is very difficult to follow in unstained sections, but after some experimenting a simple method of treatment was found by which the mycelium could be very distinctly differentiated in the host cells. Cankers were fixed in Gilson's fluid, dehydrated gradually, and cut with a slide microtome from 95 per cent. alcohol.[1] The sections were then stained one minute in a saturated solution of safranin in 95 per cent. alcohol, excess safranin removed by transferring to 95 per cent. alcohol for one minute, stained one minute in 1 per cent. gentian violet in clove oil, and cleared in clove oil, the oil washed out with xylol and the sections mounted in balsam. This method is very rapid and any number of sections can be stained at one time.

Before describing the behavior of the mycelium in the tissues it will first be necessary to review briefly the structure of a normal rose stem. Fig. 9 represents a cross-section of a stem of about the age when cankers are most frequent.

Normal Structure of the Stem. — On cutting through a rose stem with a knife, one very readily notices that it is composed of three distinct parts, (1) a rather succulent outer cylinder of bark, (2) a central soft white pith, and (3) a hard cylinder of wood between the two. The cell elements which occur in each of these will be enumerated in order, beginning with the outside.

First, the stem is covered with a smooth, thin, waterproof coat, — the cuticle. Just beneath this is the one layer of rather flat cells composing the epidermis. Next in order are three or four layers of cells with heavy walls and no intercellular spaces. This is the collenchyma. The cuticle, epidermis and collenchyma form an air-tight, water-tight covering of the stem, uninterrupted except by the stomates. These microscopic breathing pores, which are not so numerous on the stem as in the leaves, are guarded and strengthened on either side by crescent-shaped projecting cells. The structure of the stomate can best be understood by reference to the figure. It will be noticed that there is a free passage between the guard cells into the stomatal cavity beneath, and from here to the loose, thin-walled cells of the next underlying tissue, the chlorenchyma. Except under the stomates, where it is thicker, the chlorenchyma is composed of three or four layers of cells containing around the inside of the walls the green chloroplasts which give the color to the bark. Next in order are the large thin-walled cells of the inner cortex, the lowermost of which contain abundant starch grains in storage. Next there are areas of angular, very thick-walled cells, the bast fibers. The walls are so thick that there is hardly any opening (lumen) through the center. In longisection these are seen to be shaped like long, sharp-pointed pencils, with the sharp ends overlapping. Their function is to give rigidity and

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[1] Very small cankers were imbedded in paraffin, sectioned and stained in the usual way; but for larger cankers this was found to be unnecessary, and a long and tedious process.

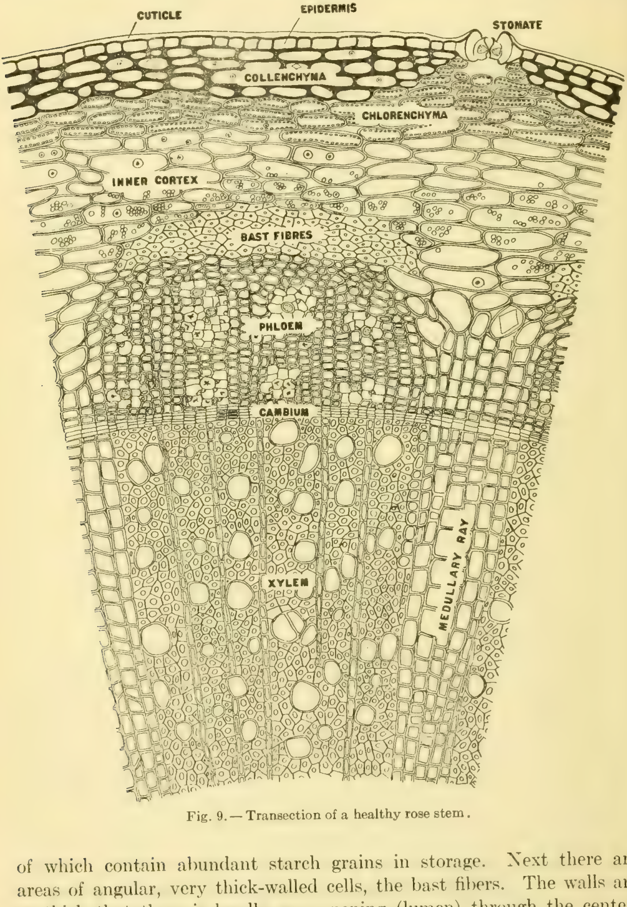
CUTICLE
EPIDERMIS
STOMATE
COLLENCHYMA
CHLORENCHYMA
INNER CORTEX
BAST FIBRES
PHLOEM
CAMBIUM
XYLEM
MEDULLARY RAY

Fig. 9.—Transection of a healthy rose stem.

strength. The areas of bast fibers do not form a complete cylinder, but the inner cortex tissue runs down between them. Just under each bast area there is a region of tissue called phloëm. It contains long tubes (sieve tubes) through which the elaborated plant food passes down through the stem from the leaves. Each sieve tube is accompanied by a line of small slender cells (companion cells), which appear in transection as though they were cut out of the corners of the sieve tubes. The remaining cells of the phloëm are box-like cells called phloëm parenchyma. The phloëm is bounded below by the cylinder of thin flat cells, the cambium, which marks the line of cleavage between the bark and wood.

The wood, or xylem, is composed mostly of four kinds of cells: (1) Box-like parenchyma cells which compose the broad medullary rays as well as the narrow rays one cell in width. (2) Long tubes of large diameter (tracheæ) through which the water mainly passes from the roots to the parts above. The walls are strengthened by spiral or annular thickenings. (3) Vertically elongated cells (tracheids) of smaller diameter and thicker walls, also water carriers. These make up the greater portion of the wood. (4) Wood fibers, somewhat smaller in diameter, with thick walls and long tapering points. They cannot be distinguished from the tracheids in transection. Although the walls of all the xylem elements are heavy, they are all marked with pits so that liquids have only a thin membrane through which they must pass to go from one cell to the next.

The pith (not shown in the figure) is composed of cells of only one kind, large or small, somewhat isodiametric (parenchyma). The walls are very thin.

Path of the Mycelium. — The germ tube, when it attacks the host, is very slender and easily passes between the guard cells down into the stomatal cavity. It could then readily pass between the loose cells of the chlorenchyma and inner cortex, but it does not choose to progress this way. Only rarely has the mycelium been seen progressing for any considerable distance between the cells, but it immediately passes *into* the cells by means of holes which it is able to dissolve through the walls. From this time on the mycelium is entirely intracellular except for the short distances through which it sometimes passes from one cell to another. It branches profusely, but the host cells do not become filled with mycelium. Rarely are more than one or two strands seen in a single cell, except in very old cankers. It is very slender and delicate at first, but in age becomes brown and takes on the various cell forms previously described for the mycelium. It seems to prefer the starch storage cells of the inner cortex, and in cankers of medium age is always found most abundantly in these cells (Fig. 10). However, the other cells are not immune. Mycelium may be found quite abundantly

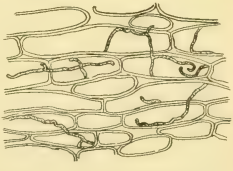

FIG. 10. — Young mycelium in the cells of the inner cortex.

in the collenchyma, the heavy walls of which seem to offer no resistance whatever to the progress of the invader. Occasionally it has been found even in the epidermal cells. The first bar to its inward progress is the area of bast fibers. It does not pass through these at once, but in very old cankers it has been observed even in the bast fibers. There is, however, an easy path between the bast areas through the flaring outer ends of the medullary rays, which do not stop at the cambium but extend up between the phloëm areas. From here the hyphæ can easily pass laterally into the phloëm. Passing down into the xylem elements the invader finds its progress made much easier by the presence of pits in all the walls. It does not confine itself to the medullary rays, but passes laterally into the other elements. The mycelium has been found in every element of the xylem, least of all, however, in the wood fibers. Often in old cankers the tracheæ may be found almost clogged with mycelium, frequently in the form of chlamydospores. The method by which it passes through the walls is shown in Fig. 11. From the xylem it passes down into the pith, where it finds progress easy through the thin walls.

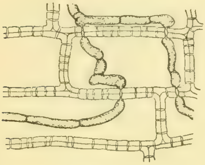

FIG. 11.—Mycelium in the cells of the medullary rays.

Effect on the Host Cells. — All of the cankers do not extend to the pith. A great many of them, for some unexplained reason, never go deeper than the bark. The fact that the affected plants stop growing, and do not send up any more shoots from below the cankers, is probably due to destruction of the phloëm, which prevents any food passing down to the lower stem or roots. The cells somewhat in advance of the invading hyphæ first become filled with a brown, finely granular substance which gradually becomes coarser and later mostly disappears, possibly being used by the parasite, and the cells are left almost empty. The starch, nuclei and chloroplasts also disappear. The walls are not affected except for the holes through which the hyphæ pass. The whole effect on the host seems to be entire disorganization of the cell contents. There is no hyperplasia, hypertrophy or other abnormal cell change in the canker. To be sure, there is often a swelling just *above* the canker, which is produced by an increase both in the size and number of cells of the inner cortex. This is, however, probably due to the amount of elaborated food which is stopped here because it cannot now continue downward on its normal course. As the canker becomes older, the cells of the bark collapse, being now empty. The cracks which then appear in the bark may be due to the contraction of the dying tissue, or to the expansion of the growing stem, or both. The cells of the xylem and pith do not collapse, but the affected tissues turn brown.

Saprophytic Life of the Fungus.

Early in this investigation it was discovered that the canker pathogene does not necessarily live all the time on the rose plant, but that it is also a natural inhabitant of the soil. This was first proved by isolating it under sterile conditions from soil 4 and 5 inches below the surface in the rose beds. Then it was found that when sterilized soil is inoculated the mycelium spreads rapidly through it and lives and grows normally there for a long time. Since these pure cultures in soil have been used rather extensively in this investigation, the method of making them is described here and omitted in all future references.

Method. — Milk bottles of 1 quart capacity were used. Thirty-three cubic inches of rose soil, moistened until muddy, was put in each bottle. The mouth of the bottle was then plugged with cotton and the whole sterilized in an autoclave. After it was cool it was inoculated by transferring a small bit of agar containing mycelium to the surface of the soil. Soil so treated becomes entirely infested in twelve to twenty-one days at ordinary room temperature.

Longevity of Mycelium in the Soil.

Before undertaking control measures it was very essential to know whether the fungus lives indefinitely in the soil, or whether it starves out and dies when the rose plant is not present to furnish nourishment. On March 27, 1917, eight milk bottles of soil were inoculated. At the end of every month clods of soil were transferred from these bottles to acidified agar plates. It has been found that when soil particles containing living mycelium are transferred to agar plates the mycelium begins to grow out on to the agar within twenty-four hours, and in a few days produces spores by which it can be definitely identified. The soil bottles were kept in a dry culture room. No water was added to them, but the soil is still somewhat moist at this writing. One year from the date of inoculation every plate isolation gave pure cultures of Cylindrocladium. There seems to be no doubt, then, that it will live for a year at least, and probably indefinitely, in the soil without the rose plant being present.

Growth on Other Substrata.

The longevity of the mycelium may possibly be increased by passing a part of its existence on substrata other than the living rose plant and the soil. The abundant growth and production of spores on dead and decaying rose twigs on the soil has previously been referred to. Dead rose leaves were sterilized and inoculated with spores in moist chambers, and it was found that the mycelium grows luxuriantly and produces some spores on them. Pods of the honey locust and leaves of the papaw tree — substrata on which the fungus was previously reported — were inoculated in the same way. The fungus grew normally on both, producing spores in great abundance on the pods, and less abundantly on the leaves. The great variety of artificial media on which it can be made to grow in the laboratory also indicates a wide range in feeding habits. Other kinds of decaying vegetable matter in the soil were not tried, but it would not be surprising if it were found capable of living on a great number of them.

Depth of Penetration of the Soil.

In the soil isolation tests the fungus was not found below 5 inches, but this was not conclusive, since the method of isolation proved not to be entirely satisfactory, and only a few isolations were made. The soil in the milk bottles was never more than 4 inches deep, but the fungus grew as luxuriantly at that depth as at the surface of the ground. In order to test its ability to penetrate to greater depth, glazed drain tiles 2 feet long were closed at the bottom with an inch of cement, filled with soil, plugged with cotton at the top and sterilized. The soil was then inoculated on the surface. Holes had been drilled at regular intervals through the side of the tiles. These were corked, and after the whole was sterilized the corks were made air-tight and water-tight by covering them with melted paraffin. In order to determine whether the fungus had penetrated to a certain depth a cork at that depth was removed, a portion of the soil next to it transferred to an agar plate, and the hole immediately made tight again, all operations being carried out under aseptic conditions. Unfortunately the soil became dry too quickly, due to the large opening at the top, and it was found necessary to pour more water on to the top of the soil. At this writing the fungus is growing throughout the entire depth of soil in the tiles, and has been isolated from the lowest holes, almost 2 feet below the surface. Whether it was washed down by the water or grew down naturally is not certain, but at present the fungus is growing normally in every particle of soil 2 feet below the surface. If it could be washed down by the water in the tiles, there is no reason why it should not be washed down by water in the rose houses. Judging from these results, and what is known about the penetration of other soil fungi, there seems to be no reason for doubting that the mycelium may exist several feet below the surface, depending to some extent on the character of the soil.

Rate of Growth of the Mycelium.

The rapidity with which mycelium grows through soil is dependent on the temperature. The optimum, maximum and minimum temperatures for growth were determined for the purpose of finding which temperatures in the greenhouse are favorable and which unfavorable to the spread of the fungus.

Method. — When the milk bottles of infested soil are kept in a dark place the progress of the white mycelium downward can be readily observed through the sides of the bottles. A number of bottles were inoculated, and when the mycelium was well started downward the limit was marked accurately by blue pencil lines around the bottles. The bottles were then placed simultaneously in incubators, ice boxes and constant temperature rooms, wherever a constant temperature could be maintained for a week at a time. A new line was drawn at the end of every forty-eight hours.

The results of this test are tabulated in Table III. An examination of this table shows that the optimum temperature for growth is 26 to 27° C, the minimum is just above 8.5°, and the maximum between 30° and 32°. At the optimum, the mycelium grows at a rate of approximately three-fourths of a centimeter per day; in other words, it requires about forty days for the mycelium to grow through 1 foot of soil. The results offer little hope of maintaining in the greenhouse a temperature very unfavorable to the growth of the fungus.

TABLE III. — *Effect of Temperature Variation on Rate of Mycelial Growth in Soil.*

TEMPERATURE, CENTIGRADE (DEGREES).	Number of Measurements.	Daily Growth in Centimeters.
5,	10	0
8.5,	10	0
14,	20	.26
16,	150	.37
21–22,	170	.50
23–25,	170	.61
25,	130	.63
25–26,	90	.68
25.5–26.5,	30	.69
26–27,	25	.74
30,	40	.25
32–36,	30	0
37.5,	10	0

Effect of freezing the Mycelium.

It is very important to know whether soil can safely be used in the benches after being frozen out of doors. The following tests were made to determine this point: —

Method. — Eight bottles, each containing 33 cubic inches of soil, were plugged, sterilized and inoculated with Cylindrocladium. After seven months the soil was thoroughly infested with the fungus, and probably contained all modifications of the mycelium which ever occur in the soil. Transfers were made and the fungus in all found to be alive. Then, before the ground froze in November, four of the bottles were exposed outside, one on top of the ground, one just under the surface, one 6 inches down, and one a foot below the surface. The other four were kept in the laboratory for controls. Some of these bottles were brought in each month of the winter to see whether the fungus was still alive.

The last test was made May 10, after the bottles had experienced the coldest winter on record in Massachusetts. The fungus was still living in the soil. Apparently, then, soil cannot be made safe by exposing it during the winter out of doors.

Thermal Death Point of Mycelium.

Anticipating soil sterilization by heat, the thermal death point for the mycelium was determined.

Method. — The same method was used as for determination of the thermal death point of spores, except that bits of agar containing mycelium were inserted into the sealed tubes, and after exposure for ten minutes to the desired temperature were transferred to sterile agar plates. If the mycelium was still alive it quickly began to spread to the agar. Temperatures between 42° and 55° C at intervals of 1° were tested.

Up to and including 48° the treatment seemed to have no effect on the mycelium. At 49° it was sometimes killed and sometimes not. It never grew after ten minutes' exposure to 50°. We may therefore consider 50° the thermal death point. It will be noticed that the thermal death points of mycelium and spores differ by only 1 degree. The mycelium tested contained, besides the ordinary white mycelium, also the dark bodies with thick walls which we have called chlamydospores and sclerotia. As was the case with spores, so also the mycelium may be killed by a longer exposure to a lower temperature. Based on an exposure during one hour, the thermal death point was found to be 48°.

DISSEMINATION.

In deciding on a method of controlling a disease it is of prime importance to find out how the pathogene is spread about, where it comes from, how it reaches the host. In the present case a threefold question is involved: (1) How did the fungus get into rose houses in the first place? (2) How is it spread from the houses of one rose grower to those of another? (3) On the premises of a single grower, how does it pass from house to house, bench to bench, or plant to plant? In the light of what has been learned concerning the life history and habits of the pathogene, we may undertake to answer these three questions.

1. ORIGINAL SOURCE OF THE PATHOGENE.

The fungus, from all that is known of its past history, is a native of America. Since it has been reported but a few times, it probably is not very common out of doors. As greenhouse roses are grown in the section of the country where it has been reported, it would not be far-fetched to imagine the fungus being carried into rose houses with rotted leaves, where it was able to adapt itself to parasitic life on the rose. It is not necessary to assume, then, that this is an imported pathogene. Early in the course of the investigation it was suspected that it might have been brought over from Europe on Manetti stocks, which are used almost exclusively by rose growers for grafting. The Manetti is moderately susceptible to the disease, as may be readily determined by examination of Manetti shoots coming from below the graft in a badly diseased house. Pure cultures have frequently been made from these shoots. Massey (1917) also made infection experiments and found Manetti roses susceptible. In the course of these investigations hundreds of Manetti stocks from Scotland were examined for lesions, numerous tissue plants were made, hundreds more were kept in moist chambers to bring out the fungus, and thousands of them watched carefully for a year after being planted in sterilized soil in order to see whether the disease developed. All results were negative, and up to the present we have no reason to suspect that the fungus is being imported on Manetti stock. It would be very helpful if we knew how widely the fungus is distributed over this country in its natural state, and whether it is being carried into the houses again and again. Various investigators have worked on the fungous flora of the soil and published lists of species isolated, but none of them mentions Cylindrocladium. This may indicate that it is only local in its distribution, or may be due merely to difficulties of isolating it. There seems to be little doubt that it infests the soil about rose houses where the disease occurs and where infested soil has been dumped out.

2. Spread from One Grower to Another.

Plants are continually being sent from one grower to another. Small cankers on these would be overlooked even if the sender was familiar with the disease. Not only could the mycelium be sent in the plant itself, but particles of soil adhering to the plants could easily carry it. It has been proved by laboratory tests that infested particles of soil may be kept dry for at least three months, and probably longer, without killing the mycelium. The disease may be spread in other ways, but this one would be sufficient to account for the present known distribution.

3. Local Dissemination.

There are a number of ways in which the fungus spreads from one part of a house to another, or from one plant to another. (*a*) It may grow for long distances through the soil and enter the plant below the surface of the soil. That infection can take place in this way has been repeatedly proved by setting clean plants in infested soil and thus producing the disease on them. (*b*) If the fungus is in the potting soil it would be effectually distributed in the beds when the plants were transplanted to them. (*c*) Where "own-root" plants are grown the soil in the cutting bench may be infested, and the disease is then carried with the cuttings when they are planted in the benches. (*d*) It is easily carried from one part of the house to another on tools, clothes and shoes of workmen.

(*e*) Insects, centipedes and worms carry the spores, as has been proved in the laboratory by permitting them to pass over sterile plates after being on dead twigs bearing spores. (*f*) The water used in watering the plants is usually driven from the nozzle with enough force to splash spores and bits of mycelium from the soil or débris on the ground up to the stems. Probably most of the stomatal infections above ground are started in this way.

The spores of many fungi are so light that they float around in the air and are wafted about by very light air currents. It does not seem likely that the spores of Cylindrocladium are carried about to any great extent in this way. They are bound together in solid heads of spores, which are probably too heavy for currents of air such as usually occur in rose houses. That they can be dislodged and blown some distance by *strong* air currents was proved in the laboratory by passing a strong current of air from a fan over spores growing on a dead rose stem, and exposing agar plates 1, 2 and 3 feet away. Colonies of the fungus developed on all of them, but it is hardly probable that so strong an air current would normally occur in rose houses. They could also be blown about on dust particles, but the soil in rose houses is rarely permitted to become dry enough to form dust.

OCCURRENCE OF TWO SPECIES OF CYLINDROCLADIUM ON ROSES.

During these investigations a second species of Cylindrocladium has frequently been isolated. It was first taken from the roots of a plant which had typical cankers on the crown. Later it was secured a number of times from crowns and from dead areas of the plant above the ground. It was commonly isolated directly from the soil in the rose beds, from the surface to 8 inches down. Except for its size, it resembles *C. scoparium* so closely that the writer was at first inclined to consider it but a dwarf variety of that species. The spores are only about one-third as large as those of *C. scoparium.* Although numerous isolations have been made, no transition forms between the two have been found. The small form has been grown through many generations in culture, and has remained constant on all media.

Infection experiments were carried out, but all attempts to produce the disease by the same inoculation methods as were used for the larger form gave only negative results. The fungus grows and produces spores on the dead tissue about wounds and on cut stubs, but seems to lack ability to spread to healthy tissue. The small form then appears to be a saprophyte, while the larger one is a parasite.

In order to determine whether there are cultural differences by which they could easily be distinguished, the two forms were grown simultaneously on five standard culture media. They show very marked diagnostic differences. Such differences in morphology, pathogenicity and cultural characters are certainly marked enough to be considered specific rather than varietal. Since no species of Cylindrocladium other than *C. scoparium* has been described, a new name, *Cylindrocladium parvum*, is proposed for this small form.

The morphological differences and the cultural characters and differences of the two species are given in parallel columns below.

MORPHOLOGICAL CHARACTERS.

Since some morphological characters vary somewhat with the conditions under which they are grown, all measurements given below were taken from potato agar plates grown simultaneously under the same conditions, and each is the average of fifty measurements.

C. scoparium.	*C. parvum.*
Size of spores, 48.8 x 5.1 μ.	Size of spores, 16.8 x 2.5 μ.
Height of conidiophore, 291 μ.	Height of conidiophore, 130 μ.
Diameter of conidiophore stalk, 6.6 μ.	Diameter of conidiophore stalk, 4.25 μ.

CULTURAL CHARACTERS.

Most soil fungi can easily be grown on a great variety of artificial media. The characters of the colony differ markedly with the medium used, and very frequently species of fungi, like bacteria, can be distinguished more easily by macroscopic cultural characters than by microscopic morphological characters. Obviously, to grow each fungus on all the possible media, or even a great number of them, would be almost an endless task. Five common media, all easy of preparation, have therefore been adopted by the writer as standard for all diagnostic work. These five are (1) potato agar (acc. Thom. Bul. 82 U. S. D. A., Bureau of An. Industry); (2) sugar potato agar (the same as the potato agar except for addition of 3 per cent. of cane sugar); (3) gelatin (150 grams gold label to a liter of water); (4) sugar gelatin (same as above with addition of 3 per cent. of cane sugar); (5) Czapek's synthetic agar (acc. Waksman in Soil Sc. 2: 113). Petri dishes, each with a single colony started at the center, were used. They were kept in the diffused light of the laboratory at the ordinary laboratory temperature.

Every reference to a color in the description below refers to the color given under that name in Ridgway's "Color Standards and Nomenclature," 1912. Color "in reverse" in these descriptions refers to the color of the colony when examined from the bottom of the dish. This color may be due to (1) a pigment in the medium itself (extra-cellular), (2) intracellular pigments (*i.e.*, the natural color of the mycelium), or (3) very frequently it is due to a combination of the two. Sometimes a distinction is made between them, but for diagnostic work such a distinction usually adds difficulty instead of simplifying determination. Most emphasis is placed on those characters which appear within the first week after the colony is made. If one has to wait two or three weeks or longer for a character to appear, the long waiting makes diagnosis tedious, and one of the principal purposes of this method of diagnosis is defeated. The more important characters for distinguishing these two species are italicized. Many minor distinguishing characters are not mentioned.

Potato Agar.

C. scoparium.	*C. parvum.*
Growth only moderately good. Starts with abundant, perfectly white, raised, aerial mycelium, but soon falls flat at the center, which becomes covered with spores after two or three days. Always more or less aerial mycelium out toward the margin, which is rather coarse and tow-like. Not a decided color in reverse during the first week, but a dilute cream color to buff. At the end of the second week it turns to avellaneous or wood brown, and *after three weeks still darker, Rood's brown. Margin of colony crenulate or wavy.*	Only moderately good growth. Mycelium finer and denser than *C. scoparium*, perfectly white. Spores produced in great abundance. *The edge entirely throughout its growth remains very even and forms a perfectly round colony.* Practically *no color* — possibly a very faint buff — *develops in reverse* even after three weeks' growth.

Sugar Potato Agar.

C. scoparium.	*C. parvum.*
Very rank growth, abundance of spores, entire plate covered in two weeks. Dense opaque color appears in reverse after three days; *vinaceous purple to hæmatite red at the edge, darkening to russet or chocolate at the center. At the end of a week a large central area appears almost black, but examined more closely shows various shades of reddish brown, chestnut and bay.* Entire reverse opaque after two weeks. The brown color is due to the extremely abundant production of sclerotia and chlamydospores on this agar.	Rank, white growth of a very much finer texture than *C. scoparium.* Abundant production of spores. *Color in reverse, white, or at most, only cream color at end of one week.* This is one of the best diagnostic characters. At the end of two weeks it has passed through gray and drab gray to a clear wood brown, with minute patches of army brown here and there which show chlamydospores under microscope. The red-brown colors of *C. scoparium* never appear.

Gelatin.

C. scoparium.	*C. parvum.*
Growth very poor, consisting of a thin covering of coarse radiating hyphæ. Very few spores. Stops growing after about ten days. Gelatin turned to a watery liquid which at the end of a week is *orange rufous, but gradually turns darker to Sanford's brown.* Liquefaction extends some distance beyond the margin of the colony.	Growth very scanty, so much so that it is necessary to look at the plate against a black background to see it at all during first week. Gelatin liquefied. No color at first, but becomes *dilute old gold by end of second week.* This medium is hardly suitable for distinguishing the two.

SUGAR GELATIN.

C. scoparium.	*C. parvum.*
Rank growth of coarse radiating aerial mycelium, but few spores. Gelatin liquefied. After about four days a *striking brilliant carmine color begins to appear in reverse, due to a pigment in the gelatin.* This gradually spreads to the whole plate *and becomes darker, an ox-blood red.* This is probably the best diagnostic cultural character for this species. The mycelium covers the plate in ten days.	Fine tangled aerial mycelium and more abundant spore production than for *C. scoparium.* Gelatin liquefied. Covers entire plate in two weeks. *At the end of a week the colonies vary from Mars yellow to raw sienna in reverse, and at the end of two weeks have darkened to amber brown and Mars yellow.* The color during the entire development of the colony is in strong contrast to the carmine and ox-blood of *C. scoparium.*

CZAPEK'S AGAR.

C. scoparium.	*C. parvum.*
Growth moderately good, aerial mycelium thin. Spores abundant. *At the end of a week the colors in reverse are much the same as for potato agar, — claret brown, russet or amber, with a brick-red color suffused through it. At the end of two weeks the center is practically black, fading through brown and red tints toward the margin.* The red color is due to a pigment in the medium; the brown, to the chlamydospores and sclerotia. Irregular edge.	Finer and denser aerial growth of mycelium. *During the first week the reverse remains pearly white; later it changes to dilute wood brown, then Rood's brown and at the end of two weeks approaches Natal brown.* None of the red tints of *C. scoparium* ever appear. Margin much more even than that of *C. scoparium.* Abundant production of spores *in distinct concentric zones.*

LATIN DESCRIPTION OF CYLINDROCLADIUM PARVUM.

Cylindrocladium parvum n. sp. *Album effusum; conidiophoris erectis, base simplicibus, apice ternate vel dichotomice ramosis, 130 x 4.25μ; conidiis cylindraciis, medio obscure 1-septatis, hyalinis, 16.8 x 2.5μ.*

Hab. in caulibus emortuis et radicibus rosarum et in humo, Massachusetts in Amer. bor. — Simile C. scopario.

CONTROL.

Every method used in the control of any fungous disease is an application of one of four principles: (1) exclusion of the fungus, (2) eradication of the fungus, (3) protection of the host, or (4) immunization of the host. Although practically all the work of the present investigation has been on the second of these principles, there are possibilities of using all four of them in the control of rose canker. These four are first considered separately below in the order named, and finally a general scheme of treatment is recommended.

Exclusion of the Pathogene.

By exclusion we mean preventing a fungus from entering a given territory in the first place, whether this territory be a country, a State, a region or only one rose house. Since this disease seems to be pretty generally distributed over the country already it is obviously impossible to exclude it from the United States, and probably from any particular State or section. But it is entirely possible to exclude it from the house of a rose grower who finds that none of his plants are already affected, or where new houses are being erected at some distance from old ones. The whole practice, then, consists of taking every possible precaution against carrying any diseased stocks, cuttings or infested soil into the house. Every plant brought in should be carefully examined, and, if there are any suspicious cankers in the bark, it should be discarded. All new plants and cuttings should be taken whenever possible only from houses known to be free from the disease.

Eradication of the Pathogene.

By eradication we mean the absolute destruction or removal of the fungus from the rose beds or from the whole house, so that it is no longer present in the plants or in the soil, pots, débris, manure or anywhere else from which it can return to the plants. The practice of this method is of course necessary only when it has been impossible to exclude the pathogene and it has become established in the house. Up to the present this has proved to be the most successful principle applied to controlling canker.

The ultimate aim is to eradicate the fungus from the plant itself, but the application of direct methods, such as excision of cankers, pruning off of dead parts, or even absolute destruction of entire plants when cankers are found on them, is altogether useless because the soil all about the plants is infested. From the soil the fungus can grow back into the roses as fast as it can be cut out. Spraying or dusting is of course useless, also, because no fungicide can reach the mycelium in the inner tissues of the plant; and also it is not possible to cover the parts of the plant below the surface of the ground where infection commonly occurs. Obviously, then, eradication resolves itself into destruction of the pathogene in the soil; in other words, soil disinfection. Of the various methods of disinfecting soil only two have appeared to be at all practicable: (1) by heat, and (2) application of chemicals. Freezing, as previously mentioned, is not effective. Desiccation would take entirely too long. Other methods are either too expensive or too difficult of application. In the course of the present investigation both heat and chemicals have been successfully used.

Disinfection by Chemicals. Laboratory Tests.

Some of the chemicals which have been used in the past for disinfecting soil for the control of other fungous diseases are formaldehyde, sulfuric acid, copper sulfate, sulfur, lime-sulfur. The results obtained by the use of these same chemicals for other fungi could not be used directly in the present investigation because every fungus differs in its resistance to a given chemical. It was first necessary to determine what concentration and what quantity of solution per cubic foot was needed to kill the fungus. These facts could be determined more accurately and conveniently in the laboratory than in the greenhouse. The method used in all these tests was as follows: —

Method. — Milk bottles, each containing 33 cubic inches of soil, were steam sterilized and inoculated from pure cultures of the fungus. When the soil was entirely infested (requiring from twelve days to three weeks) it was stirred into a loose condition with a sterile glass rod, and the proper amount of chemical in solution, at the strength to be tested, poured in under aseptic conditions. Since the soil did not dry out as rapidly in these bottles as it would under natural conditions in the greenhouse, it was emptied into sterilized porous flowerpots after a few hours. It was found after several trials that the pots dried out too rapidly if left in the open laboratory. Thereafter they were covered with bell jars which were tilted enough to allow free circulation of air beneath them, and the length of the drying process could then be regulated. After eight to ten days in the pots, clods of the soil were transferred from various portions of the pots to sterile agar plates. If the fungus was still alive it spread to the agar; otherwise there was no growth whatever from the clods. At first, the solutions were applied at the rate of 1 gallon to the cubic foot of earth. Afterwards, 2 gallons per cubic foot were used. When dry chemicals, such as sulfur, were tested the required amount was thoroughly stirred into the infested soil of the bottles with a sterile rod and no water added.

Formaldehyde. — First tests were at the rate of 1 gallon per cubic foot at the following concentrations: 1–500 (1 part of commercial formaldehyde to 500 parts of water), 1–400, 1–300, 1–200 and 1–100. None of these concentrations gave complete success. On the transfers from the last two, however, only a few of the clods contained living mycelium. This indicated a lack of complete penetration by the solution. In the next series of tests the same concentrations at the rate of 2 gallons per cubic foot were used. The 1–100 and 1–200 then gave absolute control, while the 1–300 usually did; but occasionally a single clod developed a mycelium on the agar. The death point concentration lies somewhere between 1–200 and 1–300. But to be well within the margin of safety, 1–200 (1 pint of commercial formaldehyde solution to 25 gallons of water) was decided upon as the best strength to use in the greenhouse.

Sulfuric Acid. — This chemical has been successfully used in the past in the control, particularly, of certain root diseases of nursery trees. At the rate of 2 gallons per cubic foot, concentrations of 1, 2, 3, 4, 5 and 8 per cent. were used. The 5 per cent. solution killed most of the mycelium, but not all of it. The 8 per cent. killed all of it. The death point concentration lies between 5 and 8 per cent., but such a high concentration is hardly practicable in the rose house, and the exact point was not determined.

Copper Sulfate. — Concentrations of 1, 2, 3, 4, 5 and 10 per cent. were used at the rate of 2 gallons per cubic foot. The 5 per cent. seemed hardly to check the fungus, but 10 per cent. proved entirely effective. Such a high concentration seemed prohibitive for application to soil, and no more accurate determination was made.

Lime-sulfur. — This mixture proved to be worthless, even when applied at a concentration of 1 part of commercial product (32° Baume) to 10 gallons of water, and at the rate of 2 gallons per cubic foot.

Dry Sulfur. — Finely ground sulfur flour was added to the soil and thoroughly stirred in. First, 10 grams per bottle were used, and when that proved to be ineffective 10 grams more were added, etc. All results were negative, even up to the rate of 7 pounds of sulfur to a cubic foot of soil. This test was performed at a laboratory temperature of 19° to 24° C. Perhaps if higher temperatures had been used the sulfur would have been more effective. Dry sulfur seems to be worthless at the temperatures tested.

Soot. — There is an idea prevalent among florists that soot has fungicidal value, but plant pathologists seem never to have made any extensive experiments with it. The same method and rates as for dry sulfur were tried. At the rate of 4 pounds per cubic foot soot did not kill the fungus, but at the rate of 7 pounds no growth of the pathogene occurred.

Of all the chemicals tried, formaldehyde seemed to be the only one which would give control at concentrations which could safely be used on the soil.

Greenhouse Tests with Formaldehyde.

The greenhouse tests on the use of formaldehyde were begun before the laboratory tests were completed, and at a time when it appeared that a concentration weaker than 1 pint to 25 gallons would be sufficient. As a result, the tests on a large scale were made with a concentration of about 1 pint to 40 gallons, but, on the other hand, more solution was applied per unit of soil. Two houses, each capable of growing more than 1,000 rose plants, were thoroughly soaked with the solution. One of the houses contained raised benches; the other, ground beds. Both had previously grown diseased roses. The soil was replaced by soil from outside the houses before sterilization. In the light of what we now know of the habits of Cylindrocladium, it is safe to assume that this soil was infested, because soil from the benches in previous years had been thrown out near it. After soaking the soil thoroughly the houses were closed. Fumes of formaldehyde were so strong in the closed houses that it was not possible to remain in them. After the soil had dried sufficiently both houses were planted with roses which had been potted in soil sterilized with steam, and which had been kept under conditions as sterile as possible. Three months after planting, no disease had appeared in either house. Soon afterward it began to appear in the house with the ground beds, and gradually increased until, almost a year after planting, it was generally prevalent throughout the house. In the bench house, however, no disease has as yet been found, although plant-to-plant inspections have been made frequently throughout the year. The fact that a concentration of formaldehyde weaker than 1 pint to 25 gallons controlled the disease in the bench house is probably due to the longer action of the more concentrated fumes, and probably, also, partly to the greater amount of the solution applied. The lack of control in the ground bed house can be easily explained in the light of our studies on the depth of penetration of the mycelium in the soil. The surface soil was disinfected, but it was not possible to disinfect it down as far as the mycelium grows. After the formaldehyde had evaporated the deep mycelium began to grow upward, and during that period the plants remained healthy; but, after the mycelium had grown up to the surface again, the cankers began to appear and the roses became as badly affected as before the house was treated. Two conclusions may be drawn from this experiment: (1) the soil can be disinfected effectively by the use of formaldehyde, and (2) ground beds cannot be sterilized by this method.

Disinfection by Heat. Laboratory Tests.

The feasibility of destroying any fungus by application of heat to the soil manifestly depends, first of all, on the thermal death point of all stages of that fungus. As has previously been described, this point for Cylindrocladium was found to be 50° C. This comparatively low death point indicated that the soil could be readily disinfected by steaming, because a temperature much higher than 50° C. can be easily obtained by the use of steam.

Time required to disinfect Soil by steaming. — This was further confirmed by the following tests: —

Method. — Sterile Petri dishes were filled with soil which was thoroughly infested with mycelium. After removing the lids they were subjected to steam at a temperature of 90° to 95° in an Arnold sterilizer for the desired length of time. The lids were then replaced and the soil allowed to cool, when clods of it were transferred to agar plates as described above. Exposures of five, ten, fifteen, twenty and thirty minutes were tried.

No mycelium appeared on any of the transfers, even after five minutes' exposure. Shorter periods of exposure were not tried because of the uncertainty of securing penetration by steam in less than five minutes. But, to determine what effect shorter exposures would have on mycelium, tests were made by the sealed tube method described for thermal death point tests. In these tests the mycelium was killed in less than one minute when exposed to a temperature of 95° C.

From these tests we may conclude that soil can be disinfected by steam in less than a minute if penetration is obtained. Apparently effectiveness is limited only by the time required for the steam to penetrate every particle of the soil.

Greenhouse Tests of Disinfection by Heat.

Heat may be applied to the soil by steam or by hot water. The first method has been in use in the greenhouses for the disinfection of the soil used in potting since the beginning of this investigation. Perforated steam pipes were laid a foot apart in a large pit. Soil a foot deep or more was piled over them and the steam turned into the pipes. Burlap or other coverings may be used to cover the soil and make it retain more of the steam. Soil thermometers were used to determine the temperature. It is only necessary to keep the temperature above 50° C. for ten minutes. A higher temperature, of course, makes for additional safety. The one or two hours of heating frequently recommended for other diseases is only wasted time and expense, being entirely unnecessary for this fungus. Thousands of plants have been potted in soil disinfected in this way during the last year, and canker has never appeared on any of them. No doubt other methods of steam disinfection, such as the inverted pan method, would be equally effective. Either method could probably be used just as effectively on the benches, but the formaldehyde treatment is efficient, and quicker and easier of application.

If there is any reason to suspect the presence of the fungus in the manure which is used to mulch the beds it may be disinfected in the same way as the potting soil. Soil for the cutting bench may also be treated in the same way.

The second method of applying heat — by the use of boiling water — is now being tested. It should be just as effective as steam, and at the same time much more rapid. The boiling water is forced through the water pipes ordinarily used in the house, and is applied to the soil through a hose with a long nozzle and a handle which will not become heated. The water should be applied until a thermometer inserted into the soil at any point and at any depth registers above 50° C. Higher temperatures make for additional safety. This method has the disadvantage of leaving the soil in poorer condition for working. The hot-water method is still in the experimental stage, and is not far enough along to warrant any recommendations.

Disinfection of Pots, Tools, etc.

In starting new houses with clean plants and clean soil, it is very essential that everything which is used should be free from any form of inoculum. The first danger is from pots which have been previously used, and which are apt to contain mycelium or spores in the particles of earth which still cling to them. They can be sterilized by immersing in boiling water for ten minutes. Steaming is just as effective. The method used is simply a matter of convenience.

Usually a grower, when he finds disease in his houses, finds it impracticable to destroy all his roses and start all over again. Therefore he retains some of his old houses and starts disinfection operations on one or more, from which he has removed all the plants. This inevitably results in the constant danger of carrying some infested soil or parts of plants from the infested to the clean houses. Every possible precaution should be taken to guard against this, because a failure here means that the work must all be done again. All sorts of tools offer an easy means of conveying the inoculum. Whenever possible an entirely different set of tools should be used in the clean houses, and no tools from the other houses brought in under any conditions. But, if this is not possible, the next best alternative is to sterilize the tools before bringing them in. The method of sterilizing them is not so important as thoroughness. They may be dipped in boiling water, steamed, or a barrel of Bordeaux mixture or formaldehyde — preferably stronger than 1 pint to 25 gallons in this case — may be used for soaking the tools.

It may be necessary to sterilize other things besides pots and tools, *e.g.*, boots and clothes of workmen. Every grower, after learning the habits of the pathogene, must decide for himself on the best way, under his own conditions, of keeping his houses clean.

Protection of the Host.

By protection we mean the placing of a barrier between a plant and a pathogene which would otherwise attack it and cause disease. This is well exemplified in the extensively used practice of spraying plants, the fungicide forming a poison barrier through which the fungus cannot penetrate. The humicolous habit and underground method of attack of the canker fungus seem to preclude any hope of important benefit from spraying. There is one place in the propagation of roses, however, where a fungicidal covering might be beneficial. Scions and cuttings should, whenever possible, be taken from houses known to be clean. If they are taken from houses in which the disease occurs there is always a possibility of spores being lodged on them, even where lesions have not as yet appeared. To either wash off and kill these spores or, at least, to prevent germination where they are, it has been the practice during this investigation to dip all such cuttings in a fungicide before grafting or planting.

Comparative Value of Different Fungicidal Coverings.

In order to find the best fungicide to use for dipping, and also to secure data for use in case spraying should be found advisable at any time, the comparative value of a number of fungicides was tested in the laboratory.

Method. — Glass slides were sprayed with the fungicide to be tested and permitted to dry for varying periods of time. Then spores of the fungus in a drop of water were transferred to the center of the sprayed slide, which was then kept in a moist chamber for twenty-four hours. Checks on unsprayed slides were always made at the same time. Percentages of germination were counted at the end of twenty-four hours, and observations were taken for several days to see if there was any further development; but none of the results in these tests were modified by later observations. When a dry fungicide was used it was dusted on to the slide without water. All checks in these tests germinated over 95 per cent.

Lime-sulfur. — Concentrations of 1–10, 1–30 and 1–50 commercial lime-sulfur solution were used. The 1–50 concentration proved to be useless from the start. The 1–30 seemed to check germination at first, but after it had been on the slide four or five days over 50 per cent. of the spores germinated. The 1–10 concentration entirely prevented germination when fresh, but after a week the control was erratic, with over 50 per cent. germination on some of the slides. Commercial lime-sulfur seems to be useless for control of this fungus.

Dry Sulfur Flour. — Slides were very heavily dusted and the germination tests made at about 25° C. The presence of the sulfur had no effect whatever on the spores. They germinated just as well as the checks. Dry sulfur appears to be even less effective than the lime-sulfur.

Ammoniacal Copper Carbonate. — This fungicide prevented germination twenty-four hours after being dried, but when tried a week later was only 25 per cent. efficient. This would hardly be a safe fungicide.

Lime. — Milk of lime sprayed on the slides from an atomizer prevented germination from the first, and was just as effective as Bordeaux. Milk of lime is not suitable for dipping cuttings. The lime test was made with a different end in view.

Bordeaux Mixture. — This fungicide was made up at a strength of 4–4–50. Germination tests were made every day for twenty-one days after the slides were sprayed. No germination occurred in any of these tests. These fungicidal tests clearly indicate Bordeaux mixture as the most suitable solution for dipping cuttings.

Treatment of the Walks in the House.

Undoubtedly the walks between the benches of a house which has previously grown diseased roses are infested with the pathogene. One could easily think of a great many ways in which small particles of soil from the walks could be carried into the benches. It is therefore necessary either to keep the fungus killed out of the surface of the walks by repeated applications of some fungicide or to cover the walks with some substance which will be a barrier through which it cannot pass up to the benches. In the beginning of this investigation the walks were kept sterile by frequent applications of formaldehyde. This proved unsatisfactory because the fumes of formaldehyde often injure the roses, producing dead spots on the leaves. This was abandoned and a search begun for something more suitable. Up to the present, lime gives the best promise of making a satisfactory barrier. Sterile bottle tests show that the mycelium will not grow in soil containing air-slaked lime at the rate of 1¼ pounds per cubic foot. Neither will spores germinate in the presence of lime. Until something more satisfactory is found it is recommended that all walks in the houses be kept covered with lime. Not only will this furnish an effective barrier to the fungus coming up from below, but it will also prevent growth of spores and other inocula brought in from other houses on the shoes of workmen and visitors.

Immunization of the Host.

By immunization we mean either the development of varieties of roses which are immune, — at least highly resistant, — or rendering them immune by injection or feeding through the roots with some chemical. No work has been done along either of these lines in regard to rose canker. From the first it has been noticed that some varieties of roses are more susceptible than others. No doubt in the course of time desirable varieties will be found or developed which will not suffer from canker. How soon that will be no one can predict. A rose breeder of wide national reputation told the writer that he had spent most of his life producing four or five varieties of roses. It is a long process, and until such varieties are developed it will be necessary to resort to such emergency measures as have been described in this bulletin.

Summary of Control Measures.

In the light of all that we know about rose canker and its causal pathogene the following measures are recommended for its control: —

1. Carefully inspect the rose house to see if canker is present. If not, employ every means to prevent its entering, — import as few roses as possible from other houses; examine carefully every plant brought in; reject any with suspicious dead areas in the bark.
2. If it is present on the roses it cannot be eradicated from the infected plants. The only hope lies in starting new plants from clean cuttings in clean soil, and guarding against infection at every step in the plant's development.
3. Dip the cuttings in Bordeaux mixture.
4. Sterilize the pots by dipping for ten minutes in boiling water.
5. Sterilize the potting soil and cutting bench soil by steaming to a temperature of over 50° C. for ten minutes or more. Suspected manure should be treated in the same way.
6. Use raised benches, not ground beds.
7. Remove old soil if diseased roses have been grown in it, and soak the benches thoroughly with (1) formaldehyde at the rate of 1 pint to 25 gallons, or (2) boiling water.

8. Sterilize the bench soil by one of these two methods. If formaldehyde is used, apply at the rate of 2 gallons per cubic foot. If boiling water is used, apply until every part of the soil is heated above 50° C.

9. Use a different set of tools in the clean house, or sterilize all tools before bringing them in.

10. Keep the walks in all houses covered with lime.

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BULLETIN No. 184 JULY, 1918

MASSACHUSETTS
AGRICULTURAL EXPERIMENT STATION

Late Dormant *versus* Delayed Dormant or Green Tip Treatment for the Control of Apple Aphids

By W. S. REGAN

This bulletin reports the results of comparative tests in the laboratory with commercial lime-sulfur and miscible oils for the destruction of apple aphid eggs at the late dormant period, and experiments with these materials and lime-sulfur-nicotine-sulfate combination for destroying the living aphids at the delayed dormant or green tip period. Observations on the extent of foliage injury under both laboratory and field conditions, and the manner in which these insecticides kill, are also made.

Requests for bulletins should be addressed to the
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Publication of this Document
approved by the
Supervisor of Administration.

BULLETIN No. 184.

DEPARTMENT OF ENTOMOLOGY.

LATE DORMANT VERSUS DELAYED DORMANT OR GREEN TIP TREATMENT FOR THE CONTROL OF APPLE APHIDS.

BY W. S. REGAN.

In carrying on field experiments during the summer of 1917 for the control of potato plant lice, commercial lime-sulfur solution, among other materials, was tested as to its effectiveness. Although this was used at the rate of 1 gallon to 22 gallons of water, about twice the ordinary summer strength, and in spite of the fact that every precaution was taken to drench thoroughly all parts of the plants, the percentage of plant lice killed was so small, under 10 per cent., that it could in no way be considered of value as an aphidicide at a strength safe to use upon potato foliage.

Object of Comparative Tests.

The results of these tests led the writer to question just how effective the usual dormant strength, 1 to 8, of lime-sulfur would prove against apple aphids when applied at the delayed dormant period, just after the eggs have hatched. With a view to determining this point, a number of tests have been carried out during the past several weeks. In these experiments commercial lime-sulfur solution was used alone and in combination with nicotine sulfate, and several brands of proprietary miscible oils were also tried out in comparison. Tests were also made to determine the effect of lime-sulfur and miscible oils upon the unhatched eggs.

Delayed Dormant Period indicative of Complete Hatching of Aphid Eggs.

Remarks might be prefaced here by the statement that the term dormant is taken to mean the condition of the buds in the winter or early spring before they begin to swell. By late dormant is meant the swollen condition of the buds at the time just before they split open, or in other words just before the buds show the least bit of green. This condition would normally be reached during the early part of April in Massachusetts. The term delayed dormant is applied to that period in the development of the cluster buds and foliage when they have expanded from a quarter to a half inch.

It is more or less axiomatic that the hatching of the aphid eggs is about coincident with the first splitting of the apple buds, and that by the time the buds have expanded from a quarter to a half inch, the delayed dormant period, practically all of the eggs have hatched and the young plant lice have migrated to the new growth for food. Observations have confirmed this. Twigs brought in from the field and examined on April 17 had numerous plant lice eggs upon them, but none of these had hatched. The buds were in the late dormant condition. Twigs brought in on April 19 were found to have a few newly hatched individuals, which had migrated to those buds just beginning to expand and show the least bit of green available for feeding purposes. From the 19th to the 24th of April, newly hatched aphids appeared in increasing numbers. After the latter date only a few new individuals appeared, which could be readily determined by their size. It is evident from this that under favorable weather conditions such as existed during the period mentioned the time of maximum emergence is rather brief. The presence of a few newly hatched individuals on some of the twigs on May 1 indicated that a small number of belated aphids were still hatching from the eggs, but in no case observed had the foliage expanded beyond about half an inch before hatching was completed. No viviparously produced aphids were in evidence at this time.

Object of Delayed Dormant Spraying.

In the past the practice of spraying with lime-sulfur for the control of San José scale has been confined for the most part to the dormant or late dormant season. Comparatively recently, however, the practice of delayed dormant spraying with lime-sulfur has been quite generally advocated, based on the assumption that such treatment is fully as effective as dormant or late dormant season applications against the San José scale, and that apple plant lice in their active stages would offer less resistance to this insecticide than the unhatched eggs. In other words, it is believed by some that a delayed application of lime-sulfur at full dormant-season strength, just after the buds have split open and have expanded perhaps not over half an inch, will control the San José scale, and to quite an extent the apple plant lice as well. Applications at this time, practice has shown, can be made with little or no eventual injury to the foliage. Our tests, so far as the efficiency of the delayed applications of lime-sulfur in controlling plant lice is concerned, have by no means borne out this conclusion. From the standpoint of the fungicidal value of lime-sulfur, delayed dormant applications appear to have some advantage over those of the dormant season.

On the other hand it has been recognized by some that only by the addition of nicotine sulfate to the lime-sulfur solution, when this is applied as a delayed dormant spray, can the aphids be satisfactorily controlled. This would indicate that the nicotine sulfate is mainly responsible for the control of the plant lice, and that the only reason for delaying the lime-sulfur treatment and combining it with nicotine sulfate is to make necessary only one application instead of two. Then, too, some advocate the addition of an arsenical to the above combination, at the delayed dormant period, for the control of bud moth, case bearers, etc., making possible, theoretically at least, by this insecticide combination the control of San José scale, apple aphids and certain foliage feeders by one application.

COMPARATIVE TESTS FOR THE DESTRUCTION OF APHID EGGS UNDER LABORATORY CONDITIONS.

The first tests were made for the purpose of determining the comparative efficiency of lime-sulfur solution and miscible oils against the unhatched aphid eggs. The lime-sulfur was a fresh sample of a commercial concentrate, having a density of 34° Beaumé. This was used at the strength recommended upon the container for dormant applications, 1 to 8. Two proprietary miscible oils were tested, these being diluted 1 to 15, the usual dormant-season strength. Although both samples were fresh from the manufacturers, one was evidently imperfect as there was some free oil present. In the tests, however, this imperfect sample showed to less advantage in destroying the eggs than the well-prepared sample, a rather unexpected outcome, perhaps, in view of the presence of free oil. These tests, as in the case of those following in which the aim was to determine the comparative killing efficiency, were carried out in the laboratory, where careful counts could be made and results checked. Dipping the infested apple twigs was resorted to rather than spraying, in order to insure uniformity of treatment, as by the latter method any variability of application might lead to an improper interpretation. On examination, shortly after the infested twigs were brought in from the field, it was impossible to make any estimate of the probable number of eggs that would hatch, since a large percentage of the eggs were apparently dead from some cause, as indicated by their shriveled condition. Twigs of as nearly the same size and degree of infestation as possible were selected for insecticide treatment and check, the average length of the twigs being about 8 inches. No definite percentage of efficiency can be given for the tests against the eggs. The results should be taken as merely comparative and in the way of a generalization, and are perhaps in need of further verification both in the laboratory and under field conditions. The tests against the unhatched eggs were begun when the buds were in the late dormant condition and at such a short time before hatching occurred that it was impossible to carry out verification checks. The results are given in the following table: —

Comparative Efficiency of Lime-Sulfur and Miscible Oils against Apple Aphid Eggs in the Late Dormant Period under Laboratory Conditions.

MATERIAL AND DILUTION.	Hatch on Treated Twigs.	Hatch on Check.	Injury to Twigs.
Lime-sulfur, 1 to 8, . .	No hatching on three twigs.	Twenty-nine eggs hatched,	No injury.
Miscible oil A, 1 to 15, .	Thirty-six eggs hatched on three twigs.	Twenty-four eggs hatched,	No injury.
Miscible oil B, 1 to 15, .	Seven eggs hatched on three twigs.	Fifty-four eggs hatched, .	No injury.

Discussion of Results.

While these results can hardly be accepted as conclusive, for the reasons given above, it seems evident that lime-sulfur thoroughly applied at the late dormant period is highly effective under favorable conditions in destroying the aphid eggs, and is certainly more efficient against this stage of the insect than miscible oils. Of course, in dipping the twigs it is to be expected that better results would be obtained than in the ordinary practice of orchard spraying, and it is also true that under field conditions, as will be pointed out under the topic "Action of Lime-sulfur and Miscible Oils upon the Aphid Eggs," discussed later, the intervention of rain between the time of application and the normal hatching period might alter results to a marked degree. This may account to some extent for the frequent ineffective control of apple aphids by the dormant or late dormant season lime-sulfur treatment, with which absolute thoroughness is practically impossible under field conditions, and which has also the added element of uncertainty of results due to the meteorological factor just mentioned. The hatching of a comparatively small number of eggs that have survived treatment might result in quite a severe infestation before the season is far advanced. There is also to be considered the possibility of reinfestation from other sources by migrants in the case of the green apple aphis. The destruction of the eggs or suppression of the stem mothers in the spring does not always guarantee freedom from these insects during midsummer, when supplementary treatments are sometimes desirable or necessary. The miscible oils do not appear to be very effective against the aphid eggs, even with absolute thoroughness of application; and it is probable that a sufficient number of eggs would withstand the treatment, to produce a severe infestation later in the season, unless other measures were taken for control.

Action of Lime-sulfur and Miscible Oils upon the Aphid Eggs. — Observations as to the killing power of the lime-sulfur against the aphid eggs indicate that the effectiveness of this material is due mainly to a mechanical action. On twigs examined after dipping, it was noticed that as the lime-sulfur dried it tended to stick down the eggs and mat the twig pubescence over them in such a manner that the delicate insects were apparently unable to force their way from the eggs. This fact — that the action of lime-sulfur against the unhatched eggs appears to be mainly mechanical — presents an element of great uncertainty concerning results that would obtain under field conditions. For instance, the occurrence of a rain between the time of application and the normal hatching time for the eggs might alter results to a great extent, as many of the eggs which are stuck down and potentially unable to hatch would probably thus be liberated, so that hatching might result. This contingency emphasizes the desirability of making the application of the lime-sulfur at the late dormant period if success against the aphid eggs is aimed at, in order to make the space of time between treatment and the normal hatching period as brief as possible, and to eliminate any unfavorable meteorological factors that might lessen the efficiency. As will be shown later the various elements that combine to make aphid control by lime-sulfur treatment against the eggs during the dormant or late dormant periods a matter of much uncertainty, as compared with other practices discussed later, militate against its use at either of these periods, unless no other treatment against the aphids is intended, in which case the late dormant treatment should give the most satisfactory results. No such mechanical action was evident in the case of the miscible oils, so that whatever killing of the eggs may have resulted from the use of these insecticides was undoubtedly of a chemical nature.

Comparative Tests for the Destruction of the Living Apple Aphids.

These tests were made against living apple aphids on twigs whose foliage showed varying degrees of expansion from just after the splitting open of the buds, the real delayed dormant period, up to a development of three-fourths of an inch or more, the latter being tested mainly to determine the extent of foliage injury likely to result from the treatment. Full dormant-season strength of lime-sulfur and miscible oils was used and this same strength of lime-sulfur in combination with nicotine sulfate, observations being made both as to their killing power and their effect upon the foliage. Careful counts were made of the number of living plant lice present upon the twigs before and after the dipping treatment, and from this the killing efficiency of each material could be readily estimated. The results follow: —

Comparative Efficiency of Lime-sulfur, Lime-sulfur and Nicotine sulfate, and Miscible Oils against Apple Aphids at the Delayed Dormant Period.

MATERIAL AND DILUTION.	Twig.	NUMBER OF LIVING APHIDS.		Bud Development.	Effect on Foliage.	Killing Efficiency (Per Cent.).
		Before Treatment.	After Treatment.			
Lime-sulfur, 1 to 8,	A	56	51	¼ in. open,	Slight injury,	9.1
Lime-sulfur, 1 to 8,	B	81	76	¼ to ½ in. open,	Slight injury,	9.3
Lime-sulfur, 1 to 8,	C	107	102	¼ to ¾ in. open,	Considerable injury,	9.5
Lime-sulfur, 1 to 8,	D	28	26	¼ to ½ in. open,	Slight injury,	9.2
Lime-sulfur, 1 to 8, and nicotine sulfate, 1 to 800,	A	72	0	¼ to ½ in. open,	Slight injury,	100.0
Lime-sulfur, 1 to 8, and nicotine sulfate, 1 to 800,	B	55	0	¼ to ½ in. open,	Slight injury,	100.0
Lime-sulfur, 1 to 8, and nicotine sulfate, 1 to 800,	C	45	0	¾ in. open,	Considerable injury,	100.0
Lime-sulfur, 1 to 8, and nicotine sulfate, 1 to 800,	D	59	0	½ in. open,	Slight injury,	100.0
Lime-sulfur, 1 to 8, and nicotine sulfate, 1 to 800,	E	28	0	½ in. open,	Slight injury,	100.0
Miscible oil A, 1 to 15,	A	24	0	¼ to ½ in. open,	Slight injury,	100.0
Miscible oil B, 1 to 15,	A	24	0	¼ to ½ in. open,	Slight injury,	100.0
Miscible oil B, 1 to 15,	B	34	0	¾ in. open,	Slight injury,	100.0
Miscible oil B, 1 to 15,	C	20	0	¼ to ½ in. open,	Slight injury,	100.0

Discussion of Results.

Efficiency of Lime-sulfur against the Aphids. — It is evident from the foregoing that lime-sulfur alone applied at the delayed dormant period even at full dormant-season strength is practically worthless in controlling apple aphids. Actual count shows this material to be under 10 per cent. efficient, and in every case the delicate, recently hatched aphids were the only ones affected. In addition to those killed, a few were more or less permanently incapacitated, judging from their feeble condition, but even if these were included in the "kill," it would alter the results given only slightly. The count to determine the number of plant lice killed was made at later periods of the day on which treatment was applied and on subsequent days until all deaths due to the treatment could be checked up. It should be kept in mind that all the twigs were thoroughly dipped and that the ordinary orchard spraying would probably be even less effective, unless perhaps the application of the spray under pressure might possibly dislodge some of the plant lice and thus counterbalance the less thorough application. Observations made after treatment showed that the older plant lice were apparently unaffected and were quietly feeding, except where the coating or drying out of the buds by the lime-sulfur made it necessary for them to seek suitable feeding places elsewhere.

Action of Lime-sulfur upon the Aphids. — The action of the lime-sulfur upon the young plant lice, the only stage of the active insects against which it appears to have any particular effect, seems to be mainly mechanical, in that it sticks these delicate young to the twigs in such a manner that death is probably the result of starvation. Death occurred very slowly in some cases, since the insects were often found feebly struggling to liberate themselves several hours after the treatment.

Foliage Injury by Lime-sulfur. — The effect of the lime-sulfur upon the opening foliage was noted both in the laboratory and upon field-sprayed trees, where more reliable data of this nature could be obtained. While a number of elements may enter in to affect results, such as the variety of apple, weather conditions, pressure under which the application is made, etc., our tests showed that little or no eventual injury results from the use of dormant-season strength lime-sulfur where the buds have not expanded beyond a half inch. Upon sprayed trees, where expansion beyond this point had occurred, injury was more evident, but even on treated trees, with the foliage out three-fourths of an inch to an inch or more, an examination several weeks after application showed little other than tip injury in most cases. It seems advisable, however, from the standpoint of thoroughness if for no other reason, to confine such spraying within the delayed dormant period. It was noted that the long pubescence on foliage that had expanded to about half an inch, but had not unfolded to any extent, appeared to shed the lime-sulfur readily or absorb it only in occasional spots, which resulted in injury at these points; whereas the shorter, matted pubescence of the bark and bud scales absorbed it readily, and on this account more injury was often caused to those buds just splitting open than to those slightly more advanced.

Efficiency of Lime-sulfur and Nicotine sulfate combined against the Aphids. — Previous tests have shown that nicotine sulfate at the dilution 1 to 800 is practically a perfect aphidicide. The addition of lime-sulfur probably increases its efficiency very little, so that the only logical reason for the use of this combination at the delayed dormant period is for the purpose of saving labor by combining two operations — the San José scale treatment and aphid treatment — in one. Laboratory tests where absolute thoroughness of application by dipping was possible showed this combination to be 100 per cent. effective. The effectiveness of this combination under field conditions would depend mainly on thoroughness of application.

Action of the Lime-sulfur-nicotine sulfate Combination upon the Aphids. — As already indicated the action of lime-sulfur in killing the aphids appears to be mainly mechanical, — by sticking them to the plant so that in most cases death is probably the result of starvation. The action of the nicotine sulfate in killing the aphids is rather slow, requiring from about half an hour to twenty-four hours or more for different individuals. Immediately after the dipping there was no evidence that the treatment had any effect upon the aphids. In about fifteen minutes, however, considerable restlessness was apparent and inside of half an hour a number of the plant lice had begun to drop from the twigs, some being precipitated rather forcefully as if from strong muscular contraction. These lay struggling feebly but unable to crawl, gradually becoming dark colored and motionless. Those plant lice that survived the treatment for a number of hours appeared after a few hours to be paralyzed and incapable of either locomotion or feeding, but were feebly moving their legs and antennæ and excreting honey dew in abnormally large amounts. An examination of the twigs forty-eight hours after treatment showed all the plant lice to be dead. The fact that nicotine sulfate kills rather slowly may account for the occasional reports that this material is ineffective against plant lice. Examination of treated plants shortly after application might readily lead to this conclusion, but if sufficient time is allowed before examination there will be no question as to its effectiveness.

Foliage Injury by the Lime-sulfur-nicotine-sulfate Combination. — A comparison of the effects from the use of full dormant-season strength lime-sulfur alone and in combination with nicotine sulfate on apple foliage in various stages of development from the first splitting of the buds to a development of an inch or more showed no noticeable difference. Even at the latter period of development the amount of foliage injury was not serious.

Efficiency of Miscible Oils against the Aphids. — Tests against the living aphids with two brands of proprietary miscible oils showed a killing efficiency of 100 per cent. for each of these.

Action of Miscible Oils upon the Aphids. — The killing action of miscible oils upon the aphids seems to be almost instantaneous. In fact on twigs examined shortly after dipping no movement of the aphids could be noticed. The action is evidently of a strictly chemical nature.

Foliage Injury by Miscible Oils. — While spraying with miscible oils for the control of San José scale is usually confined to the dormant or late dormant season, our tests would indicate that this material, if perfect, can be used at full dormant-season strength during the delayed dormant period with no more injury to the foliage than results from the use of lime-sulfur. At this period in tests conducted both in the laboratory and in the field only slight tip injury resulted; but where the foliage had developed to three-fourths of an inch or more, the injury from the use of the miscible oils seemed to be slightly greater than that resulting from the lime-sulfur treatment. Even this was not serious and was readily overcome as the season advanced. From the foregoing it is evident that where the use of miscible oils for orchard spraying is practiced the most economical time for application is during the delayed dormant period, when one application will serve for both the San José scale treatment and aphid control.

CONCLUSIONS.

1. The delayed dormant period is usually indicative of the complete hatching of apple aphid eggs. At this time the buds have expanded from a quarter to a half inch.

2. Lime-sulfur solution at full dormant-season strength is less than 10 per cent. effective against the living aphids when applied at the delayed dormant period.

3. Lime-sulfur applied at the late dormant period, before the buds split open and just before the hatching of the aphid eggs, appears to be highly effective, under favorable conditions, in destroying the eggs, but the elements of thoroughness of application and unfavorable meteorological conditions present such uncertainty as to results that this treatment can hardly be recommended as an effective control.

4. If lime-sulfur is to be used as a control for San José scale and no special treatment for apple aphids is to be made later, best results against aphids, if present, are likely to be obtained by a late dormant-season application just before the eggs hatch. Treatment at this time should also be thoroughly effective against the scale.

5. The application of the lime-sulfur (1 to 8) and nicotine sulfate (1 to 800) combination applied at the delayed dormant period gives practically a perfect control for apple aphids and makes unnecessary a separate earlier application of lime-sulfur for San José scale. The per-

centage of efficiency will depend mainly upon thoroughness of application.

6. The ordinary dormant-season treatment of apple orchards with miscible oil against San José scale, if applied thoroughly at the delayed dormant period, should result in practically a perfect control of apple aphids also.

7. Delayed dormant applications of full dormant-season strength lime-sulfur, lime-sulfur and nicotine sulfate combined, and miscible oils, if perfect, can be made without material injury to apple foliage. Even when the foliage is considerably more advanced, little severe injury usually results. This fact, if taken into account, might make unnecessary separate applications for early and late budding varieties. As the foliage becomes more advanced, however, the success of the treatment involves greater difficulty, since the aphids are very difficult to reach when they have the spreading leaves for protection.

8. The action of lime-sulfur in destroying both the aphid eggs and living insects appears to be mainly mechanical, by sticking them to the twigs.

9. The action of nicotine sulfate in killing the living aphids is slow, requiring from about half an hour to twenty-four hours or more for different individuals. Death appears to be due to paralysis.

10. Miscible oils are practically instantaneous in their killing action against the living aphids. The action is probably of a chemical nature.

Acknowledgments.

The writer is greatly indebted to Mr. A. I. Bourne of the Massachusetts Agricultural Experiment Station staff for assistance in carrying out the insecticide tests, and to Dr. H. T. Fernald for his kind suggestions and assistance.

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BULLETIN No. 185 JULY, 1918

MASSACHUSETTS
AGRICULTURAL EXPERIMENT STATION

The Inheritance of Seed Coat Color in Garden Beans

By J. K. SHAW and JOHN B. NORTON

This bulletin is a record of the inheritance of seed coat color among certain varieties of garden beans as shown by intercrossing these varieties. There are presented also certain hypotheses to account for the facts observed. It should be of interest to students of genetics, more especially those engaged in or contemplating investigations with this particular group of plants.

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Publication of this Document
approved by the
Supervisor of Administration.

BULLETIN No. 185.

DEPARTMENT OF HORTICULTURE.

THE INHERITANCE OF SEED COAT COLOR IN GARDEN BEANS.

BY J. K. SHAW AND JOHN B. NORTON.

Introduction.

Investigation of inheritance in garden beans at this station was begun in 1907 by Mr. C. S. Pomeroy, then assistant horticulturist, who made several crosses during that summer and grew the F_1 generation in 1908. Additional crosses were made during the same summer. In the fall of 1908 this crossed seed and that of the F_1 generation above referred to fell into the hands of the senior writer, who has been responsible for the conduct of the investigations since. In the summer of 1913 the junior author came into the work and has since borne a large share. During all this time Prof. F. A. Waugh has had general supervision, and his helpful criticisms and suggestions made from time to time are gratefully acknowledged.

Review of Literature.

A number of investigators have given time to the study of the inheritance of seed coat color in beans. Mendel (1) after his classical experiments with peas gave some attention to beans, but he discovered little beyond the fact that he had here a more complex problem than that presented by peas, and he was not able to apply the simple 3:1 formula to explain his results.

Emerson (2) made many crosses of different horticultural varieties, and observed among other things the behavior of seed coat color. He considered that the mottled offspring exhibited characters not visible in either parent. In a later paper (3) the same author gives the numbers of seeds resulting from a cross of a dark brown and a yellow brown, and from a cross of a black and a white variety. The results of these crosses were similar to those of Burpee Stringless, Giant Stringless, Challenge Black Wax and White Marrow.

Further investigation showed Emerson that the theory of mosaics could not explain the behavior of mottled beans resulting from crosses of non-mottled parents, and he advanced (4) a theory suggested by Shull, which supposed one factor was responsible for mottling in fixed races and a different factor responsible for mottling in heterozygous forms mentioned above, which is visible in heterozygous individuals only.

In another paper (5) Emerson discusses this theory, and develops another theory suggested by Spillman, which supposes mottling to be due to two factors which may exist separately in the heterozygous mottled forms or coupled in those forms which breed true to the mottled characters. By this theory the facts reported in the present paper may be explained.

Tschermak carried on numerous investigations of the inheritance of seed coat color in beans along with others with stocks and peas. In his most recent paper (22) he analyzes his results, and is able to account for most of them in a satisfactory fashion by means of simple Mendelian factors.

Shull (17) advanced the hypothesis of the appearance of the mottling factor only in heterozygous individuals referred to above.

Kajanus (13) reports investigations of the inheritance of colors and color patterns in garden beans, especially of the behavior of a violet marbled type of mottling due apparently to distinct factors. He reports also on the chemical nature of the pigments involved.

Jarvis (11) and Tracy (19) have given excellent descriptions and a quite stable nomenclature of common bean varieties, and Freeman (7) describes several types of the Mexican frijoles and teparies, *P. acutifolius* var. *latifolius.*

Methods.

At first, commercial seed procured from the trade was used, but beginning in 1909 steps were taken to breed pure races, and earlier crosses made with plants grown from commercial seed were, so far as possible, repeated. Evidence indicated that a few of these earlier parents were probably hybrids, and such crosses have been ignored in the consideration of results. In all cases the plants used for crossing have been externally true to type, but as will appear later, it is probable that in some varieties two or more races have been encountered. In such cases no external differences have been observed in the parent plants, though their behavior on crossing revealed different genetic composition.

In making the crosses the procedure of Emerson has been generally followed; that is, emasculation and pollination have been performed in one operation. This method has given sometimes 30 per cent. or more of successful attempts, and at other times a very low percentage of successes. This is probably due in part to unfavorable environmental conditions, and in part to variations in the procedure, — usually the selection of a female blossom that was not sufficiently mature. In a few cases the resulting plants have been like the female parent, indicating that self-fertilization had taken place before the foreign pollen was introduced, or at least before it could take effect. Some of the crossing was done in the field and some in the greenhouse during the winter. In the latter case the blossoms were not covered, while in the former a one-fourth pound manilla bag was tied tightly over the flower stalk for five or six days, after which it was torn open, and, if the attempt seemed successful, left to indicate the seed pod at the time of harvest.

In all cases four generations from the cross have been grown. In each generation except the fourth a certain number of plants chosen more or less at random have been self-fertilized by enclosing them during the blossoming period in cheesecloth or, in a few cases, waxed paper sacks. Neither of these is satisfactory. Both weaken the plant, the waxed paper sacks more than the cheesecloth ones. It has been the invariable observation that there is a progressive weakening of the plants through the four generations. First generation crosses are invariably strong, vigorous plants, often seemingly more vigorous than the parent varieties, while the fourth generation plants are decidedly weak and unproductive. Whether this is due to the repeated self-fertilization or to the weakening effect of covering the plants does not appear. Possibly both have contributed to the result observed.

The blossoms have been more or less infested with thrips. None have been observed on covered plants, but it is entirely possible that there may have been cases of such infestation, and that in rare cases a grain of foreign pollen was introduced in the blossom of a plant supposed to be self-fertilized. A few irregularities that may have been due to such a cause have been observed. Nevertheless, the probability that such cases are extremely rare is indicated by a number of considerations. Bean blossoms are commonly self-fertilized before they open, and, according to our observation, thrips does not infest unopened buds. The pollen-carrying ability of thrips cannot be large, and it appears that it does not commonly enter beneath the bags, or it would have been observed in the many examinations of the covered plants. And finally, cases arousing suspicion of the entrance of foreign pollen are extremely rare.

Recording Data.

The method of securing records of the plants has been previously described (16). It consists, essentially, in assigning to the expression of each supposed Mendelian character a special letter designation. The plants have been examined for blossom color, pod color, and for seed coat color. This involves going over the plants not less than three times, and in most cases two examinations have been made for each character, involving examination of the plants six times. In order to identify the individual plants, each is assigned a number in order. The seeds are planted about 6 inches apart, and a small tag bearing its number is early attached to every fifth plant. Thus, in order to ascertain the number of any plant, one has to examine only a very few plants along the row before finding one bearing a tag with its number. When any plant is self-fertilized the fact is noted on the card along with the rest of the record for that plant. A record of the original crosses is kept so that one may trace readily the ancestry of any individual plant back to the original parents.

As soon as the seed was well matured a single bean from each plant representative of those on that plant has been selected and preserved. Unfortunately mice gained access to a portion of these seed samples and destroyed many of them. Still, samples representing a majority of the plants grown escaped destruction and are available for examination. Many of the pigments found in the seed coats are subject to change with age, and due allowance must be made in the study of old seed.

It has been said that an attempt was made in recording observations to designate the expression of each independent character by a separate letter. The letter used, the color which each stands for, and the name of a variety bearing each color character are as follows: —

	Seed Coat Color.	*Found in —*
A.	White,	Davis Wax.
B.	Buff,	Blue Pod Butter.
C.	Yellow,	Giant Stringless.
D.	Medium or bright red,	Red Valentine.
E.	Dark or purplish red,	Mohawk.
F.	Coffee brown,	Burpee Stringless.
G.	Black,	Challenge Black Wax.
H.	Olive,	Certain crosses.
L.	Eyedness,	All eyed beans.
O.	Dark mottled,	Red Valentine.
P.	Light mottled,	Golden Carmine.

	Flower.	
A.	White,	All white and eyed sorts.
B.	Light pink,	Burpee Stringless.
C.	Pink,	All black seed sorts.
D.	Crimson,	Blue Pod Butter.
E.	Waxy pink,	Certain crosses.

The first eight letters stand for separate and quite distinct colors, most of which may be found in one or more of the varieties used. The color H does not appear in any of the varieties used, but does appear in several of the crosses. Attempts have been made to distinguish different eye sizes in eyed beans. There is no doubt that eye size is inherited, but the data secured do not appear clear and definite enough to warrant any positive conclusions; therefore only a brief general report on different eye sizes is made.

Mottled beans are of two distinct kinds, — one, designated as "dark mottled," includes those sorts where the darker color or colors predominate, of which there are many varieties other than Red Valentine, the one cited; the other, called "light mottled," includes those varieties of the Horticultural type. The different blossom colors have been more fully explained in a previous publication (15).

Varieties used.

During the eight years that the investigations have been in progress twenty-one varieties have been used in the crosses yielding results deemed worthy of consideration. A few others have been used in a very limited way. Including reciprocals, more than 120 different crosses have been made, some of which have been repeated two or three times.

The principal varieties used, their blossom and seed coat color, and the letters used to designate them, are as follows: —

Variety.	Blossom.		Seed Coat.	
	Color.	Letter.	Color.	Letter.
Black Valentine,	Pink,	C	Black,	G
Blue Pod Butter,	Crimson,	D	Buff,	B
Bountiful,	Pink,	C	Greenish buff,	B
Burpee Kidney,	White,	A	Red mottled eye,	EOL
Burpee Stringless,	Light pink,	B	Coffee brown,	F
Challenge Black Wax,	Pink,	C	Black,	G
Creaseback,	White,	A	White,	A
Currie,	Pink,	C	Black,	G
Davis Wax,	White,	A	White,	A
German Black Wax,	Pink,	C	Black,	G
Giant Stringless,	Light pink,	B	Yellow,	C
Golden Carmine,	Light pink,	B	Light mottled,	EP
Golden Eyed Wax,	White,	A	Yellow eyed,	CL
Keeney Rustless,	White,	A	Dark red eyed mottled,	EOL
Longfellow,	Light pink,	B	Red mottled,	DO
Low Champion,	Light pink,	D	Red,	D
Mohawk,	Light pink,	B	Dark red mottled,	EO
Prolific Black Wax,	Pink,	C	Black,	G
Red Valentine,	White,	A	Red mottled,	DO
Wardwell,	White,	A	Dark red mottled eye,	EOL
Warren,	Light pink,	B	Dark red,	E
Warwick,	Light pink,	B	Red mottled,	DO
White Marrow,	White,	A	White,	A

The nomenclature is according to Jarvis (11), and for a full description of the several varieties the reader is referred to his paper or that of Tracy (19).

An examination of the above table reveals several more or less constant correlations between blossom color and seed coat color. All white or eyed beans are accompanied by white blossoms. So far as the knowledge of the writers goes this is always true, unless it may be in some cases of eyed beans, when the eye is unusually large. With this reservation no certain exceptions have been observed among either commercial varieties or the crosses made. With the exception of Red Valentine, all totally pigmented or mottled beans show more or less color in the blossom. A few plants in certain lots of Red Valentine have shown slight color in the blossom, while in other lots a careful examination showed no colored flowers. As is shown later, more than one strain of Red Valentine has been encountered, and this may account for the occasional appearance of slightly tinged flowers. There are a number of commercial varieties having pigmented seeds and white flowers.

In these varieties black beans and pink flowers always go together, and this seems to be generally the case among commercial varieties whether the bean is solid black or black mottled, unless the mottling is confined to a distinct eye. Our records show a number of instances where a black or black mottled bean is said to have been accompanied by a white flower, but such cases are very few among many where the flower is pink, and we are inclined to ascribe them to erroneous observations, usually of blossom color. Certain pigmentation of the plant as a whole seems to accompany certain blossom colors. The crimson flower of Blue Pod Butter is always accompanied by a deep purplish coloration of the entire plant. It is probable that the factor producing the pink flower and black coloration in the seed coat always causes also fine purplish lines on the stems and possibly a darker foliage than is found in non-pigmented plants.

Pod color is undoubtedly independent of other coloration of the plant, except that green podded plants have slightly darker green foliage than wax podded varieties.

The purplish coloration characteristic of the foliage of Blue Pod Butter, found also in crosses when it is one of the parents, extends to the seed pods whether they are green podded or wax podded. In many cases a more or less obscure reddish or crimson splashing appears on the outside of the seed pod. This is frequently, but apparently not always, associated with mottled seeds. It is clearly seen in varieties of the Horticultural class. Often it does not show until the pod is about to ripen, and disappears with complete maturity. On account of these facts it has been found difficult to secure accurate data bearing on the genetic behavior of this character. Moreover, our attention has been directed more especially to other characters. Our observations indicate that it is a character worthy of more careful study directed especially upon this point.

As has been previously intimated, the inheritance of pigmentation in beans is exceedingly complicated. Many independent factors are involved, and through various interrelations of these, varied colors and color patterns are produced. These colors and color patterns are not limited in number to the letter designations given. To put it in another way, many of the letters have been used to designate more than one color, or colors, of different genetic origin, but always similar colors, and usually those that on first encountering we could not certainly differentiate. For example, the B seed colors of Blue Pod Butter and Bountiful are similar in appearance, but of entirely different genetic constitution, and can be with some difficulty distinguished from each other in the field. It has been the aim to use a given letter within a given cross always for the same color character, and it is thought that this has been usually successful.

The appearance of pigment in the seed coat of beans is usually the expression of a complex factor or the concurrence of several factors. In the absence of any one of the elements of this factor complex the beans are unpigmented. If this be the case, crosses of non-pigmented beans may give rise to pigmented offspring. One such cross has been encountered in this work, that of Davis Wax X Michigan White Wax. This does not signify that such crosses are rare, for only three have been made in the course of this work, the other two, Creaseback X Burpee's Fordhook Favorite, and White Marrow X Burpee White Wax, yielding only non-pigmented offspring. As previously reported, numerous crosses of plants bearing white flowers have given rise to plants with pigmented flowers, but all these have been accompanied by pigmented seeds. Had the possible results from intercrossing non-pigmented beans been realized from the first a much larger number of such crosses would have been attempted.

CROSSES OF PIGMENTED WITH NON-PIGMENTED BEANS.

We have a white-coated bean whenever one or more elements of the factor complex for pigmentation are absent, and crosses of such plants with pigmented plants have shown dominance of pigmentation. The proportions of pigmented and non-pigmented beans in the F_2 generation have been approximately 3:1, yet most crosses show departures from this ratio that, in view of the large numbers involved, may be significant. These results are shown in Table I. In some crosses there is an excess of pigmented beans and in others a deficiency. We have been unable to settle upon any theory that will explain in detail these seeming irregularities. If the non-pigmented parent lacks more than one element of the pigment complex an excess of non-pigmented beans in F_2 would result, — an explanation of the observed excess of white beans that may or may not be correct. It is possible that the excess of pigmented beans might be explained on the basis of a complex pigmentation factor were it thoroughly understood, but we are unable at present to offer adequate explanation of all the departures from a 3:1 ratio that have been observed.

Some of the crosses involving Creaseback show very great departures from a 3:1 ratio. In 97*a* and 331*a* the number of white beans is very few. Both these must be crosses, for Creaseback is a pole bean, and pole beans have appeared in considerable numbers in 97*a*, and most of the beans in 331*a* were entirely unlike Warwick, the female parent. This behavior of Creaseback will be more fully discussed later.

TABLE I. — *Crosses of Pigmented with Non-pigmented Beans.*

Cross No.	PARENT VARIETIES.	F₂.		F₃ and F₄ (Pigmented Parents only).	
		Pigmented.	White.	Pigmented.	White.
33	Blue Pod Butter (P) X White Marrow (W), .	77	35	410 286	157
34	White Marrow (W) X Blue Pod Butter (P), .	57	23	87 196	38
	Totals, ...	**134**	**58**	**497**	**195**
	Ratios, ...	*2.31* :	*1*	*2.55* :	*1*
67	Burpee Stringless (P) X White Marrow (W), .	54	17	302 68	93
68	White Marrow (W) X Burpee Stringless (P), .	46	14	175 205	61
	Totals, ...	**100**	**31**	**477**	**154**
	Ratios, ...	*3.22* :	*1*	*3.10* :	*1*
129	Currie (P) X White Marrow (W), . . .	122	49	159 57	59
	Ratios, ...	*2.49* :	*1*	*2.70* :	*1*
184	White Marrow (W) X German Black Wax (P),	84	32	22 3	6
	Ratios, ...	*2.63* :	*1*	*3.67* :	*1*
230	White Marrow (W) X Golden Carmine (P), .	12	7	13 110	3
	Ratios, ...	*1.71* :	*1*	*4.33* :	*1*
249	Golden Eyed Wax (P) X White Marrow (W),	118	36	185 70	56
250	White Marrow (W) X Golden Eyed Wax (P),	18	4	129 63	27
	Totals, ...	**136**	**40**	**314**	**83**
	Ratios, ...	*3.40* :	*1*	*3.78* :	*1*
268	White Marrow (W) X Keeney Rustless (P), .	14	7	81 18	21
	Ratios, ...	*2.00* :	*1*	*3.86* :	*1*
298	White Marrow (W) X Prolific Black Wax (P), .	33	11	63	28
	Ratios, ...	*3.00* :	*1*	*2.25* :	*1*
309	Red Valentine (P) X White Marrow (W), .	71	22	66 88	34
310	White Marrow (W) X Red Valentine (P), .	33	9	56 28	17
	Totals, ...	**104**	**33**	**122**	**51**
	Ratios, ...	*3.15* :	*1*	*2.39* :	*1*
31	Blue Pod Butter (P) X Creaseback (W), .	144	65	520 260	134
32*a*	Creaseback (W) X Blue Pod Butter (P), .	5	3	26 11	1
32	Creaseback (W) X Blue Pod Butter (P), .	73	30	155	49
	Ratios, ...	*2.43* :	*1*	*3.16* :	*1*
97	Challenge Black Wax (P) X Creaseback (W),	145	37	238 136	65
	Ratios, ...	*3.92* :	*1*	*3.66* :	*1*
97*a*	Challenge Black Wax (P) X Creaseback (W),	101	1	29 60	2
247	Golden Eyed Wax (P) X Creaseback (W), .	10	3	65 97	19
	Ratios, ...	*3.33* :	*1*	*3.42* :	*1*
296	Creaseback (W) X Prolific Black Wax (P), .	26	17	–	–
	Ratios, ...	*1.53* :	*1*	–	–

TABLE I. — *Crosses of Pigmented with Non-pigmented Beans* — Concluded.

Cross No.	PARENT VARIETIES.	F_2.		F_3 and F_4 (Pigmented Parents only).	
		Pigmented.	White.	Pigmented.	White.
331	Warwick (P) X Creaseback (W),	30	9	7 27	2
331*a*	Warwick (P) X Creaseback (W),	38	1	131 104	5
332	Creaseback (W) X Warwick (P),	48	14	103	40
	Totals (omitting 331*a*),	**78**	**23**	**110**	**42**
	Ratios,	*3.39* :	*1*	*2.62* :	*1*
73	Challenge Black Wax (P) X Davis Wax (W),	243	84	242 329	73
	Ratios,	*2.89* :	*1*	*3.32* :	*1*

THE INHERITANCE OF PIGMENT PATTERNS.

The disposition of pigments over the surface of the bean may be even, in which case we call it self-colored; or the pigments may be irregularly disposed, revealing the separate colors in short stripes or splashes, when we have a mottled bean. The mottling or the self-color may be limited to a more or less well-defined area around the hilum, giving us an eyed bean. These two pigment patterns, mottling and eyedness, will be separately considered.

Mottling.

There are many varieties of beans with mottled seeds. The colors involved are various, and the type of mottling differs in different varieties. The inheritance of the various colors is dealt with in a later section. The various types of mottling are without difficulty separated into two classes, — a light mottling shown in various varieties of the Horticultural class, and a dark mottling shown by Red Valentine, Refugee and many others. Many crosses involving both types of mottling have been made, and the mottling always breeds true. There are also many crosses where only non-mottled parents have yielded mottled beans, both of the light and dark mottled types. But in no case have these mottled beans bred true. This is in accord with other investigations, and a theory to account for the facts has been set forth by Emerson (4) on the suggestion of Spillman. This theory supposes that mottling is brought about by two factors, Y and Z, which are coupled in the case of true-breeding mottled varieties, but may be separately borne by distinct varieties, and in such cases are inherited independently. Individuals from such crosses bearing both Y and Z are mottled and always heterozygous, while those bearing either one are not mottled. Whether or not this is the final and complete explanation of mottling in beans, it serves to explain the results thus far obtained.

The following crosses of mottled beans have bred true, yielding only mottled progeny: —

Cross No.	Parent Varieties.	Total Number of Progeny.
215	Golden Carmine X Mohawk,	77
258	Red Valentine X Keeney Rustless,	109
262	Wardwell X Keeney Rustless,	168
273	Mohawk X Red Valentine,	78
274	Red Valentine X Mohawk,	281

Golden Carmine is of the light mottled type, and Keeney Rustless and Wardwell are mottled-eyed beans; all the others are of the common dark mottled type.

Table II. shows the results of crossing mottled and self-colored varieties. In all such crosses the F_1 generation has yielded only mottled beans. The F_2 generation has been composed of mottled and self-colored beans in proportions approximating 3:1, though rather wide departures will be noted. These departures are subject to the same comments as those in crosses of pigmented and non-pigmented beans shown in Table I. All extracted self-colored beans have bred true and mottled beans have proved homozygous in mottling in some cases and heterozygous in others, as shown in the table. None of the mottled varieties in this table are of the light or Horticultural type. Wardwell and Keeney Rustless have mottled eyes. Golden Eyed Wax has a self-colored eye, while the other self-colored varieties are totally pigmented and of various colors.

Table II. — *Crosses of Mottled with Self-colored Beans.*

Cross No.	Parent Varieties.	F_2.		F_3 and F_4.	
		Mottled.	Self.	Mottled.	Self.
19	Blue Pod Butter (S) X Mohawk (M),	8	–	55 43	21
20	Mohawk (M) X Blue Pod Butter (S),	7	4	1	–
	Totals,	**15**	**4**	**55**	**21**
	Ratios,	*2.75*	: *1*	*2.62*	: *1*
23	Blue Pod Butter (S) X Red Valentine (M),	23	7	26 15	9
	Ratios,	*3.29*	: *1*	*2.89*	: *1*
29	Blue Pod Butter (S) X Warwick (M),	38	10	90 157	37
30	Warwick (M) X Blue Pod Butter (S),	106	51	16 109	3
	Totals,	**144**	**61**	**106**	**40**
	Ratios,	*2.36*	: *1*	*2.65*	: *1*
54	Mohawk (M) X Burpee Stringless (S),	24	4	54	–
57	Burpee Stringless (S) X Red Valentine (M),	32	13	82 8	24
58	Red Valentine (M) X Burpee Stringless (S),	63	30	180 127	31
	Totals,	**95**	**43**	**262**	**55**
	Ratios,	*2.21*	: *1*	*4.76*	: *1*

TABLE II. — *Crosses of Mottled with Self-colored Beans* — Concluded.

Cross No.	PARENT VARIETIES.	F_2.		F_3 and F_4.	
		Mottled.	Self.	Mottled.	Self.
95	Challenge Black Wax (S) X Warwick (M),	34	13	136 179	52
	Ratios,	*2.62* :	*1*	*2.61* :	*1*
115	Currie (S) X Mohawk (M),	158	41	68 12	34
116	Mohawk (M) X Currie (S),	20	6	26 9	7
	Totals,	**178**	**47**	**94**	**41**
	Ratios,	*3.79* :	*1*	*2.29* :	*1*
119	Currie (S) X Red Valentine (M),	116	50	117 201	46
120	Red Valentine (M) X Currie (S),	287	151	77 176	19
	Totals,	**403**	**201**	**194**	**65**
	Ratios,	*2.00* :	*1*	*2.98* :	*1*
193	Giant Stringless (S) X Mohawk (M),	12	2	19 16	7
194	Mohawk (M) X Giant Stringless (S),	13	2	67 99	23
	Totals,	**25**	**4**	**86**	**30**
	Ratios,	*6.25* :	*1*	*2.86* :	*1*
197	Giant Stringless (S) X Red Valentine (M),	25	9	54	36
198	Red Valentine (M) X Giant Stringless (S),	30	5	53	22
	Totals,	**55**	**14**	**107**	**58**
	Ratios,	*3.93* :	*1*	*1.84* :	*1*
287	Prolific Black Wax (S) X Red Valentine (M),	27	14	95 122	28
288	Red Valentine (M) X Prolific Black Wax (S),	180	75	136 72	47
	Totals,	**207**	**89**	**231**	**75**
	Ratios,	*2.33* :	*1*	*3.08* :	*1*
348	Blue Pod Butter (S) X Refugee (M),	5	7	23 12	14
	Ratios,	*.71* :	*1*	*1.64* :	*1*
27	Blue Pod Butter (S) X Wardwell (M),	10	1	94 56	28
28	Wardwell (M) X Blue Pod Butter (S),	35	11	78 111	30
	Totals,	**45**	**12**	**172**	**58**
	Ratios,	*3.75* :	*1*	*2.97* :	*1*
61	Burpee Stringless (S) X Wardwell (M),	15	7	11 9	2
	Ratios,	*2.14* :	*1*	*5.50* :	*1*
191	Giant Stringless (S) X Keeney Rustless (M),	4	1	43 41	13
	Ratios,	*4.00* :	*1*	*3.31* :	*1*
201	Giant Stringless (S) X Wardwell (M),	42	21	81 55	34
	Ratios,	*2.00* :	*1*	*2.38* :	*1*
244	Wardwell (M) X Golden Eyed Wax (S),	21	12	44 18	19
	Ratios,	*1.75* :	*1*	*2.31* :	*1*
357	Longfellow (M) X Golden Eyed Wax (S),	4	2	3 19	3
	Ratios,	*2.00* :	*1*	*1.00* :	*1*

In cross 54, Mohawk X Burpee Stringless, in the F_3 and F_4 generations, 54 plants yielded only mottled beans. This is explained by the fact that only two parent plants were involved, and both happened to be homozygous for mottling.

In Table III. are shown the results obtained from crosses of mottled and white varieties. In all such crosses the F_1 beans have been mottled,, and all extracted whites have bred true. Extracted self-colored beans have sometimes bred true and sometimes yielded self-colored and white in approximately a 3:1 ratio, never mottled beans. As shown in the table, the usual result in F_2 seems to be a 9:3:4 proportion.

TABLE III. — *Crosses of Mottled with White Beans.*

Cross No.	Parent Varieties.	F_2.			F_3 and F_4 (Mottled Parents only).		
		M.	S.	W.	M.	S.	W.
141	Davis Wax (W) X Keeney Rustless (M),	17	–	2	11	–	3
					18		
230	White Marrow (W) X Golden Carmine (M),	11	5	7	7	2	2
						101	
309	Red Valentine (M) X White Marrow (W),	82	22	34	1	–	3
					149		
309*a*	Red Valentine (M) X White Marrow (W),	38	–	13	45	–	26
					81		
310	White Marrow (W) X Red Valentine (M),	16	7	9	17	5	6
					5		10
						21	6
					28		
327	Wardwell (M) X White Marrow (M),	32	1	5	14	36	13
					15		3
					8		
366	White Marrow (W) X Burpee Kidney (M),	6	2	3	10	3	3
					18		8
					6	4	
331	Warwick (M) X Creaseback (W),	5	25	8	9	3	–
331*a*	Warwick (M) X Creaseback (W),	8	24	1	121	–	3
					16	11	
					124		
332	Creaseback (W) X Warwick (M),	8	12	3	5	10	6
					19		37
						29	14

Cross 141, Davis Wax X Keeney Rustless, yielded no self-colored beans. It will be shown later that Davis carries the coupled factors YZ, and as soon as pigment is introduced yields mottled beans. This being true, and Keeney Rustless also bearing YZ, no self-colored beans can appear. In cross 309 it is evident that two strains of White Marrow are involved, the one in 309*a* being like Davis Wax in bearing the coupled YZ, and the other strain only one of these factors, thus permitting the appearance of self-colored beans. In crosses 331 and 332 there are certain irregularities due to Creaseback that will be discussed later.

Most of our crosses among self-colored beans have yielded only self-colored progeny, no mottled or white beans appearing. A list of such crosses follows: —

Cross No.	Parent Varieties.	Total Number of Progeny.
43	Burpee Stringless (S) X German Black Wax (S), ...	419
44	German Black Wax (S) X Burpee Stringless (S), ...	437
50	Golden Eyed Wax (E) X Burpee Stringless (S), ...	410
55	Burpee Stringless (S) X Prolific Black Wax (S), ...	75
81	Challenge Black Wax (S) X Golden Eyed Wax (E), ...	459
87	Challenge Black Wax (S) X Prolific Black Wax (S), ...	–
112	Golden Eyed Wax (E) X Currie (S), ...	879
189	Giant Stringless (S) X Golden Eyed Wax (E), ...	266
190	Golden Eyed Wax (E) X Giant Stringless (S), ...	213
237	Golden Eyed Wax (E) X Prolific Black Wax (S), ...	419
346	Black Valentine (S) X Prolific Black Wax (S), ...	108
349	Blue Pod Butter (S) X Warren (S), ...	18
350	Bountiful (S) X German Black Wax (S), ...	11
351	Bountiful (S) X Prolific Black Wax (S), ...	75
354	German Black Wax (S) X Bountiful (S), ...	81
362	Prolific Black Wax (S) X Bountiful (S), ...	56

Crosses of a number of self-colored varieties have yielded only mottled individuals in F_1, and mottled and self-colored individuals in F_2, in what seems to be roughly a 1:1 proportion. These are shown in Table IV.

TABLE IV. — *Crosses of Self-colored Varieties yielding Mottled Progeny.*

Cross No.	Parent Varieties.	F_2.		F_3 and F_4 (Mottled Parents only).	
		M.	S.	M.	S.
1	Blue Pod Butter X Burpee Stringless, . .	159	146	165	170
2	Burpee Stringless X Blue Pod Butter, . .	78	88	28	22
	Totals, ...	**237**	**234**	**193**	**192**
3	Blue Pod Butter X Challenge Black Wax, .	36	39	25	30
4	Challenge Black Wax X Blue Pod Butter, .	92	125	38	28
	Totals, ...	**128**	**164**	**63**	**58**
5	Blue Pod Butter X German Black Wax, .	7	16	8	5
6	German Black Wax X Blue Pod Butter, .	48	27	26	35
	Totals, ...	**55**	**43**	**34**	**40**
11	Blue Pod Butter X Giant Stringless, . .	2	1	11	12
12	Giant Stringless X Blue Pod Butter, . .	26	51	20	32
	Totals, ...	**28**	**52**	**31**	**54**
15	Blue Pod Butter X Golden Eyed Wax, . .	20	22	10	11
16	Golden Eyed Wax X Blue Pod Butter, . .	25	32	43	42
	Totals, ...	**45**	**54**	**53**	**53**
21	Blue Pod Butter X Prolific Black Wax, . .	69	59	27	42
22	Prolific Black Wax X Blue Pod Butter, . .	84	91	39	51
	Totals, ...	**153**	**150**	**66**	**93**
343	Low Champion X Blue Pod Butter, . .	36	26	38	48

Extracted self-colored individuals have bred true, and no unpigmented beans have appeared. We may note at this point that Blue Pod Butter is one of the parents of all these crosses. The explanation of this is that Blue Pod Butter is the only self-colored bean bearing the factor Y, all other self-colored varieties carrying the other factor for mottling, designated as Z; and as, according to Emerson's theory, mottling can result only when Y and Z are both present, the variety named is the only self-colored variety that can produce mottling when crossed with the other self-colored variety used. While the proportion 1:1 is held quite closely when the total numbers of reciprocal crosses are considered, it may be noted that in all cases except the crosses involving Blue Pod Butter with Golden Eyed Wax and Challenge Black Wax there is an alternate preponderance of mottled and self-colored beans in the two members of the reciprocal crosses, a fact that may have a significance, or be only a chance occurrence.

TABLE V. — *Crosses of Self-colored with White Beans yielding Mottled Progeny.*

Cross No.	Parent Varieties.	F₂.			F₃ and F₄ (Mottled Parents only).		
		M.	S.	W.	M.	S.	W.
7	Blue Pod Butter (S) X Davis Wax (W), . .	14	3	6	36 19	–	21
8	Davis Wax (W) X Blue Pod Butter (S), . .	38	13	16	18 40 8	9 3	12 13
33*a*	Blue Pod Butter (S) X White Marrow (W), .	–	41	24	–	–	–
33	Blue Pod Butter (S) X White Marrow (W), .	74	17	22	93 82 135 145	12 60	23
34	White Marrow (W) X Blue Pod Butter (S), .	40	17	23	21 47 31 85	9 7	8 22
67	Burpee Stringless (S) X White Marrow (W), .	38	16	17	124 102 11 23	48 5	38 34
68	White Marrow (W) X Burpee Stringless (S), .	35	11	14	100 59 11	– 19	23
73	Challenge Black Wax (S) X Davis Wax (W), .	182	68	84	72 32 40 209	29	28 6
129	Currie (S) X White Marrow (W), ...	63	58	49	35 9 3	31 12	30
184	White Marrow (W) X German Black Wax (S),	59	19	32	17 3	– 1	4
249	Golden Eyed Wax (S) X White Marrow (W), .	46	22	23	49 52 28	14	18 15
250	White Marrow (W) X Golden Eyed Wax (S), .	12	6	4	21 53 14	8	9 12
298	White Marrow (W) X Prolific Black Wax (S), .	19	14	11	10 20 4	2	6 4

At least two of the white varieties used in this work, Davis Wax and White Marrow, seem to carry the factors for mottling, and in most cases they have yielded in F_2 mottled, self-colored and white beans in what is probably a 9:3:4 ratio. Crosses with these varieties are shown in Table V. All extracted whites have bred true, and extracted self-colored beans have either bred true or yielded self-colored and mottled beans in approximately a 3:1 ratio. In several cases mottled beans have been extracted which bred true, thus indicating that in some cases at least both Davis and White Marrow carry both Y and Z; that is, they are really mottled beans lacking pigment. In cross 33*a* no mottled beans appear, probably because Blue Pod Butter and the particular strain of White Marrow involved carry the same mottling factor, and both likewise lack the other one. It is certain that a different plant of White Marrow was used and one from a commercial stock, while in 33 and 34, individuals of a selfed strain were used, and this strain was not derived from the plant used in 33*a*.

In the cross of Golden Eyed Wax X White Marrow (Table V.) the behavior as regards mottling is as expected from the above considerations. In another cross of what were supposed to be the same varieties no white beans appeared. The behavior of the progeny was exactly what would be expected of a cross of Golden Eyed Wax X Warwick. Warwick and White Marrow were grown next to each other in the row, thus making it easy to make an error in obtaining blossoms. We are therefore inclined to believe that the irregularity was due to such an error in pollination.

According to Emerson's theory of mottling all mottled varieties have the constitution PYZ in which formula P indicates the factor for pigmentation and YZ the coupled factors for mottling. Non-mottled pigmented beans can have only one of these factors bearing either PYz or PyZ. White beans may be either pYZ, pYz or pyZ. The possible results of intercrossing these types of beans are as follows: —

Case No.	Cross Constitution.	Color of Beans.	Proportion of Mottled, Self and White in F_2.		
			M.	S.	W.
1,	PYZ X PYz,	m X s,	3	1	–
2,	PYZ X PyZ,	m X s,	3	1	–
3,	PYZ X Pyz,	m X s,	3	1	–
4,	PYZ X pYZ,	m X w,	3	–	1
5,	PYZ X pYz,	m X w,	9	3	4
6,	PYZ X pyZ,	m X w,	9	3	4
7,	PYZ X pyz,	m X w,	9	3	4
8,	PYz X PyZ,	s X s,	2	2	–

Case No.	Cross Constitution.	Color of Beans.	Proportion of Mottled, Self, and White in F_2.		
			M.	S.	W.
9,	PYz X Pyz,	s X s,	–	4	–
10,	PYz X pYZ,	s X w,	9	3	4
11,	PYz X pYz,	s X w,	–	3	1
12,	PYz X pyZ,	s X w,	6	6	4
13,	PYz X pyz,	s X w,	–	3	1
14,	PyZ X Pyz,	s X s,	–	4	–
15,	PyZ X pYZ,	s X w,	9	3	4
16,	PyZ X pYz,	s X w,	6	6	4
17,	PyZ X pyZ,	s X w,	–	3	1
18,	PyZ X pyz,	s X w,	–	3	1
19,	Pyz X pYZ,	s X w,	9	3	4
20,	Pyz X pYz,	s X w,	–	3	1
21,	Pyz X pyZ,	s X w,	–	3	1
22,	Pyz X pyz,	s X w,	–	3	1

The results secured in the work here reported can be quite satisfactorily explained on the above theory. All crosses of mottled beans have yielded only mottled beans, as shown on pages 67 and 68.

Some crosses of self-colored beans have yielded mottled progeny. (See Table IV.) In most such crosses Blue Pod Butter is one of the parents. If it has the constitution PYz then the other members of the crosses must be PyZ. Self-colored beans of either of the above types, when crossed with mottled beans, have yielded mottled and self-colored beans in the proportion of approximately 3:1, as shown in Table II.

The mottling factors of white beans are not so readily determined, and there seems to have been more than one strain of some of the white varieties used. Davis Wax seems always to carry the coupled factors YZ. (See Tables III. and V.) It is probable that there are three strains of White Marrow, as follows: —

Constitution.	Found in Crosses —
pYZ,	33, 34 (case 10), 67, 68, 129, 184, 249, 250, 298 (case 15), 309*a* (case 4).
pyZ,	230, 309, 310, 366 (case 6).
pYz,	33*a* (case 11).

Crosses involving Creaseback. — In crosses involving Creaseback the beans in F_1 have always been black or nearly so. In the cross with Challenge Black Wax the beans were nearly black, but with faint signs of mottling. In later generations black beans predominate, with some signs of indistinct mottling in some cases. The occasional appearance of mottling suggests that one or both mottling factors are carried by Creaseback. The fact that mottling appears with Blue Pod Butter which in all other crosses seems to carry the Y only, and with Challenge Black Wax which carries the Z, indicates that Creaseback must carry both Y and Z, or that more than one strain has been used. If coupled factors are present there should appear beans breeding true to the mottled character. No such cases have been clearly shown. If we assume that the appearance of solid or nearly solid black beans is due to the presence of an additional factor X, which renders the black color epistatic to mottling, we have a hypothesis that is fairly well supported by the limited data available. These data are shown in Table VI. Crosses 31 and 32 were among the earlier crosses made, and while no individual records of mottled beans in F_2 were kept, it is evident that mottling did occur, but it was very faint and nearly obscured by black in most cases. There were a few dark mottled beans, however, and one of these being selfed gave the proportions of mottled, self-colored and white beans shown in the table. In crosses 31 and 32, Table VI., Creaseback may have the formula yZ, for in this case, assuming the presence of X in Creaseback

TABLE VI. — *Crosses involving Creaseback.*

Cross No.	Parent Varieties.	F_2.			F_3 and F_4.					
					Mottled parents.			Self parents.		
		M.	S.	W.	M.	S.	W.	M.	S.	W.
31	Blue Pod Butter X Creaseback, .	–	101	53	9	7	3	4	59	22
									279	78
									217	
32	Creaseback X Blue Pod Butter, .	–	5	3	–	–	–	–	28	1
									11	
31*a*	Blue Pod Butter X Creaseback, .	6	42	12	–	–	–	1	26	6
									134	18
									117	
32*a*	Creaseback X Blue Pod Butter, .	8	71	30	–	–	–	12	8	2
								1	9	3
									160	37
									155	
97	Challenge Black Wax X Creaseback,	–	150	42	–	–	–	–	–	–
97*a*	Challenge Black Wax X Creaseback,	8	38	–	–	–	–	4	14	1
								6	10	
97*b*	Challenge Black Wax X Creaseback,	8	52	1	–	–	–	9	2	1
								5	3	
									44	
97*c*	Challenge Black Wax X Creaseback,	30	113	36	–	–	–	54	123	33
								11		3
								10	3	
								1	9	
									14	3
									132	
247	Golden Eyed Wax X Creaseback, .	–	10	4	–	–	–	5	43	17
								2	76	
									4	1
									26	
296	Creaseback X Prolific Black Wax, .	–	22	15	–	–	–	–	–	–

and a formula of Yz for Blue Pod Butter, we should get a proportion of 6 mottled, 42 self-colored, and 16 white, which proportion is rather closely approximated in both crosses 31 and 32. The crosses with Challenge Black Wax seem to present different combinations of characters. Number 97 was one of the early crosses, and the obscure mottling earlier referred to appeared, but no record was preserved. Cross 97*c* was made later when the appearance of mottling was more clearly appreciated, and these two may be of the same nature. Crosses 97*a* and 97*b* are probably alike, and the failure of any white seeded beans to appear in 97*a* due to chance. We are unable to explain the small proportion of white beans, unless it may be on the basis of difference in the pigment complex earlier referred to.

In cross 247, Golden Eyed Wax X Creaseback, no mottled beans are recorded in F_2, but in later generations obscurely mottled beans do appear, and it is not impossible that a closer study of the F_2 generation would have revealed their presence. Unfortunately these samples are among those destroyed.

This variety is worth further study and a full comprehension of its behavior, and the reasons therefor would probably throw much light on the inheritance of pigmentation, not only in beans but in a general way.

Another variety that apparently behaves in a similar way is Crystal Wax. Owen[1] reports that crossed with Round Pod Kidney (Brittle Wax) there appeared in F_1 colored and dark mottled, nearly black beans, and the F_2 plants were 10 mottled, 24 self-colored and 10 white, nearly all of the self-colored seeds being black.

Mottling Patterns.

Among the commercial varieties of mottled beans two prevailing types of mottling are evident. Both show as a ground color a sort of buff or ecru. In the darker mottling, represented by Red Valentine and Refugee, this color prevails over only a small part of the seed, while in the lighter, represented by varieties of the Horticultural class, it covers three-fourths or more of the surface. Some evidence indicating that this buff color is the same thing in both light and dark mottled beans will be presented later. When crossed, the darker type of mottling seems to behave as a simple dominant in the single cross that has been made.

TABLE VII. — *Light and Dark Mottling.*

Cross No.	PARENT VARIETIES.	F_2.		F_3 AND F_4.		
				O PARENTS.		o PARENTS.
		O.	o.	O.	o.	o.
215	Golden Carmine (o) X Mohawk (O), .	1	1	33 6	10	21

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[1] Report N. J. Experiment Station, 1906, p. 456.

In the above table and the one following, O represents the dark or Red Valentine type of mottling, and o the light or Horticultural type.

The behavior of White Marrow and Davis Wax in crosses with colored beans indicates that both these varieties possess one or both of the factors for mottling, as has already been shown (page 73). There is no evidence that the factor, O, for dark mottling is present in either variety. Crosses of these two varieties with Blue Pod Butter (Table V.) yield no dark mottled beans, indicating that Blue Pod Butter does not possess the O factor. Therefore Blue Pod Butter may be described as PYzo, and the two white varieties as pyZo or pYZo. All dark mottled varieties may be described as PYZO. All other pigmented self-colored sorts used in these experiments may be described as PyZO, except Warren, which is probably like Blue Pod Butter so far as mottling factors are concerned.

The results of crossing White Marrow and Davis Wax with a number of pigmented varieties are shown in Table VIII. A study of the results here shown indicates that the factor O just described is associated with the Z mottling factor. If this be the case, on crossing a colored bean PyZO with a white bean pYZo we should get in F_2 a proportion of six

TABLE VIII. — *Mottling Factors in White Beans.*

Cross No.	Parent Varieties.	F_2.				F_3 and F_4.							
						O Parents.				o Parents.		S Parents.	
		O.	o.	S.	W.	O.	o.	S.	W.	o.	W.	S.	W.
230	White Marrow (W) X Golden Carmine (M).	–	11	5	7	–	–	–	–	7 107	22	4 3	1
309	Red Valentine (M) X White Marrow (W).	33	9	–	13	22 25 4	4 11	–	16	19 33	11	–	–
366	White Marrow (W) X Burpee Kidney (M).	6	–	2	3	21 3 3	7 2	9	– 2 2	–	–	5 21	2
327	Wardwell (M) X White Marrow (W).	10	–	2	4	30	–	23	14	–	–	11	4
327*a*	Wardwell (M) X White Marrow (W).	17	4	–	2	12	3	2	2	9	2	–	–
141	Davis Wax (W) X Keeney Rustless (M).	14	4	–	2	5 16	6 1	–	3	–	–	–	–
67	Burpee Stringless (S) X White Marrow (W).	39	9	16	17	51 17 18	25 5	30 9 6	29 9	126	39	52 28	21
68	White Marrow (W) X Burpee Stringless (S).	23	12	12	14	25	17	18	–	94 18 11	30	78	27
184	White Marrow (W) X German Black Wax (S).	42	17	19	32	1 3 5	0 0 2	4 4 5	6 0 0	15	5	13 5	5
73	Challenge Black Wax (S) X Davis Wax (W).	141	51	68	84	46 27 19 4 9 7 2 6	13 18 3 4	23 9 11 3	28 6 1 3	21 209	3	84 55	34
249	Golden Eyed Wax (S) X White Marrow (W).	20	26	22	33	29	14	10	16	61 28	16	45	26
250	White Marrow (W) X Golden Eyed Wax (S).	8	5	6	4	17 5	4	2 2	7 1	38 30	11	38 52	7

dark mottled, three light mottled, three self-colored, and four white, which is in harmony with the results shown in the table. No dark mottled beans could breed true, and no extracted light mottled beans could yield self-colored offspring.

In cross 230 Golden Carmine, which must be, according to the foregoing hypothesis, of the constitution PYZo, when crossed with White Marrow yields no dark mottled beans, but does yield self-colored beans. White Marrow must therefore be pyZo, and the proportion in F_2 one of 9:3:4. The self-colored beans in F_3 and F_4 are from the heterozygote parents, and are not, like the other light mottled beans, extracted from the heterozygote. In cross 309*a* no self-colored beans are produced. Red Valentine must, from its appearance, be PYZO, and White Marrow must be pYZo. The theoretical F_2 proportion — 9 dark mottled, 3 light mottled and 4 white — is closely approximated. In cross 366 Burpee Kidney is like Red Valentine and White Marrow pyZo as in cross 230, the non-appearance of light mottled beans in F_2 being due to small numbers. In cross 327 Wardwell, a bean with a dark mottled eye, when crossed with White Marrow yields no light mottled beans, while in 327*a* light mottled beans appear, but no self-colored ones. This can be explained on the assumption that in cross 327 the White Marrow plant used was of the pyZo strain, while in 327*a* a plant of the constitution pYZo was used.

In cross 141, Davis Wax X Keeney Rustless, no self-colored beans are produced, and as in all other crosses of Davis Wax it has the formula pYZo, while Keeney is PYZO.

In crosses 67 and 68 Burpee Stringless must be PyZO and White Marrow pYZo. On the assumption that the O and Z factors are associated or coupled, the failure of light mottled progeny to appear in the proportion 18:0:6:9 must be due to the small numbers involved, and this lot belong properly on the second line above, it being of the same constitution as the F_2 heterozygote. Similar cases are found in crosses 181 and 73. The appearance of a single self-colored plant from a light mottled parent in cross 68 is unexplained unless it be a stray plant. Such a plant undoubtedly did appear in a lot all of which were supposed to be from a light mottled parent plant. It is not thought that these seeming irregularities are sufficient to throw serious doubt upon the general theory of the inheritance of types of mottling, but they are recorded in order to fully present the facts as they have appeared.

Besides the types of mottling here discussed a wholly different type has been encountered in certain crosses involving White Marrow. This is a fine marbling or cloudy mottling, bluish, brownish or bluish black in color. It is similar to that shown by the variety Cut Short. Data bearing on this are limited. In a cross of Prolific Black Wax X White Marrow this type of mottling appeared, sometimes covering the whole bean and sometimes confined to a limited area, giving an eyed bean. Three plants with this type of mottling yield the parent type and white in the numbers of 6:9, 20:4 and 5:1, respectively. They have been extracted from both self-colored and dark mottled parents.

The Behavior of Eyedness.

In many varieties of pigmented beans the pigment is centered around the hilum, producing the eyed bean. The eye may be restricted to a very small area near the hilum, or it may extend over nearly the entire bean, and in some varieties there are found detached circular spots on the dorsal or lateral portion of the bean. In most if not all such cases the pigmented area around the hilum is large. Leopard Wax is a variety of this sort. The pigments and different types of mottling found in totally pigmented beans may occur in any size or type of eye. In most cases the edge of the pigmented area is not sharply defined, but in others it is clear-cut and definite. No varieties with this sharply defined edge have been used in the crosses here reported, but they have been extracted from certain of the crosses.

The behavior of crosses of totally pigmented and eyed beans made in the course of this work is shown in Table IX. It closely resembles that of a monohybrid, but the proportions in the F_2 generation are somewhat at variance with the expectation. The total number of plants in F_2 is 1705, and the ratio 3.9:1. Nearly all crosses show an excess of totally pigmented beans. The progeny of heterozygous parent plants in F_3 and F_4, totaling 2,069, show a ratio of 3.02:1. Why this difference in the behavior in heterozygous plants occurs, it is impossible to explain at present. We can only repeat the suggestion made with reference to results shown in previous tables (page 65). All extracted eyed beans have bred true, and in all cases the beans of the F_1 generation have been totally pigmented.

In Table X. are shown the results of crosses of eyed and white beans. In all these crosses totally pigmented beans are produced in F_1. In the F_2 generation totally pigmented, eyed and white beans are produced in the proportions shown. It is probable that these plants are of four classes and may yield all three types, totally pigmented and eyed, totally pigmented and white, or they may be homozygous for total pigmentation. Eyed beans may be pure or may yield eyed and white.

These results are in harmony with the conclusions of Emerson (5) and Tschermak (22), and indicate that total pigmentation is dependent upon two characters, — P for pigmentation and T, which spreads the pigment over the entire bean, and the absence of which, Pt, causes an eyed bean.

As has been the experience of previous experimenters we have found no beans with the formula pt. However, we have used only five white seeded sorts, and only three of these at all extensively. The white beans extracted from an eyed parent in crosses 249, 268 and 327 should be of this constitution, and should yield no totally pigmented beans on crossing with an eyed form. Unfortunately, none of these few white seeded plants were self-fertilized or retained for seed, making it impossible to test this theory.

The fact that eye sizes differ has been mentioned. While too few accurate data have been collected in the course of these experiments to make any definite report, it is evident that these eye sizes are inherited

TABLE IX. — *Crosses of Eyed with Self-colored Beans.*

Cross No.	PARENT VARIETIES.	F₂.			F₃ and F₄ (Totally Pigmented Parents).		
		Totally Pigmented.		Eyed.	Totally Pigmented.		Eyed.
15	Blue Pod Butter X Golden Eyed Wax, . .	41		7	79 65		37
	Ratios, ...	*5.9*	:	*1*	*2.1*	:	*1*
16	Golden Eyed Wax X Blue Pod Butter, . .	117		35	200 80		77
	Ratios, ...	*3.3*	:	*1*	*2.6*	:	*1*
50	Golden Eyed Wax X Burpee Stringless, .	31		4	125 154		38
	Ratios, ...	*7.7*	:	*1*	*3.3*	:	*1*
189	Giant Stringless X Golden Eyed Wax, . .	110		28	31 22		10
	Ratios, ...	*3.9*	:	*1*	*3.1*	:	*1*
190	Golden Eyed Wax X Giant Stringless, . .	42		15	46 81		13
	Ratios, ...	*2.8*	:	*1*	*3.5*	:	*1*
237	Golden Eyed Wax X Prolific Black Wax, .	87		26	103 93		34
	Ratios, ...	*3.3*	:	*1*	*3.0*	:	*1*
81	Challenge Black Wax X Golden Eyed Wax, .	157		43	79 80		26
	Ratios, ...	*3.7*	:	*1*	*3.0*	:	*1*
112	Currie X Golden Eyed Wax, ...	186		53	225 130		74
	Ratios, ...	*3.5*	:	*1*	*3.0*	:	*1*
240	Red Valentine X Golden Eyed Wax, . .	191		40	70 192		27
	Ratios, ...	*4.8*	:	*1*	*2.6*	:	*1*
239	Golden Eyed Wax X Red Valentine, . .	256		48	114 36		38
	Ratios, ...	*5.3*	:	*1*	*3.0*	:	*1*
52	Keeney Rustless X Burpee Stringless, . .	14		3	60		13
	Ratios, ...	*4.7*	:	*1*	*4.6*	:	*1*
191	Giant Stringless X Keeney Rustless, . .	5		–	59 55		9
	Ratios, ...	–		–	*6.6*	:	*1*
258	Red Valentine X Keeney Rustless, . .	15		2	54 26		25
	Ratios, ...	*7.5*	:	*1*	*2.2*	:	*1*
27	Blue Pod Butter X Wardwell, ...	4		1	13 131		5
	Ratios, ...	*4.0*	:	*1*	*2.6*	:	*1*
28	Wardwell X Blue Pod Butter, ...	39		12	123 104		46
	Ratios, ...	*3.3*	:	*1*	*2.7*	:	*1*
61	Burpee Stringless X Wardwell, ...	25		9	53 8		8
	Ratios, ...	*2.8*	:	*1*	*6.6*	:	*1*
201	Giant Stringless X Wardwell, ...	43		22	120 42		35
	Ratios, ...	*2.0*	:	*1*	*3.4*	:	*1*

in definite proportions. Larger eye sizes show more tendency to break up than smaller ones. It is probable that the formula Pt above referred to should be taken to indicate the smallest eye size observed, and that

TABLE X. — *Crosses of Eyed with White Beans.*

Cross No.	PARENT VARIETIES.	F₂.			F₃ AND F₄.					
					TOTALLY PIGMENTED PARENTS.			EYED PARENTS.		
		Totally Pigmented.	Eyed.	White.	Totally Pigmented.	Eyed.	White.	Eyed.	White.	Self.
141	Davis Wax X Keeney Rustless, .	17	1	2	45	4	18	–	–	–
					14	5				
247	Golden Eyed Wax X Creaseback, .	9	1	4	45	4	18	12	–	–
					68	20				
					3		1			
					4					
249	Golden Eyed Wax X White Marrow,	51	17	23	19	5	12	12	3	–
					9	4		10		
					133		44			
					11					
250	White Marrow X Golden Eyed Wax,	15	3	4	62	31	21	56	–	–
					4	6				
					25		8			
268	White Marrow X Keeney Rustless, .	4	8	7	26	6	9	39	9	–
					7		2			
					18					
327	Wardwell X White Marrow, . .	25	9	5	22	4	5	20	–	–
					23		7	21	9	
							7			6

the larger eye sizes are due to the presence of other factors. If there are two additional factors for eye size they could yield four homozygous eye sizes, and there are without doubt at least that number known. There could be also four heterozygous forms which might exhibit other sizes. Thus the following formulæ may express various eye sizes: —

FORMULA.	Eye Size.	Found in —
Ptrs, ...	Very small eye, ...	Maule Butter.
PtRs, ...	Small eye, ...	Golden Eyed Wax.
PtrS, ...	Medium eye, ...	Keeney Rustless.
PtRS, ...	Large eye, ...	Leopard.

Of course the characters R and S could be carried by any totally pigmented bean, but could not appear until a cross with some eyed form was made.

THE INHERITANCE OF PIGMENTS.

Thus far we have dealt with the inheritance of pigment patterns without reference to the particular colors involved. All the pigment patterns studied carry many different colors. So far as we have been able to see, there is no relation between the behavior of pigment patterns and the pigments themselves. We will now consider the manner in which the several pigments behave in inheritance.

It is evident that there are two classes of pigments found in the varieties of colored beans used in these experiments. One class appears as some shade of red or purplish red, and is found in Red Valentine, Golden Carmine, Mohawk and similar colored varieties. This pigment is readily soluble in water, as shown by laboratory tests and indicated by the readiness with which such seeds fade when exposed to the action of dew and rain in the field. The light reds, such as Red Valentine, take on the purplish color when treated with alkali, and the purplish reds of Mohawk change to a bright red in acid solutions. The former are unchanged in acid solutions and the latter in alkaline solutions. These reactions indi-

TABLE XI. — *Crosses of Blue Pod Butter with other Self-colored Varieties.*

Cross No.	Parent Varieties.	F₂.		F₃ and F₄ (Various Colored Parents only).	
		Various Other Colors.	B.	Various Other Colors.	B.
1	Blue Pod Butter X Burpee Stringless,	176	56	231 156	68
2	Burpee Stringless X Blue Pod Butter,	116	40	37 95	22
3	Blue Pod Butter X Challenge Black Wax,	57	18	33 43	22
4	Challenge Black Wax X Blue Pod Butter,	174	53	51 98	20
5	Blue Pod Butter X Currie,	25	7	3 38	2
6	Currie X Blue Pod Butter,	71	11	87 134	26
9	Blue Pod Butter X German Black Wax,	10	6	31	–
10	German Black Wax X Blue Pod Butter,	63	12	45 23	15
11	Blue Pod Butter X Giant Stringless,	8	1	30 38	15
12	Giant Stringless X Blue Pod Butter,	45	30	–	–
21	Blue Pod Butter X Prolific Black Wax,	123	48	82 236	26
22	Prolific Black Wax X Blue Pod Butter,	101	34	26 51	10
15	Blue Pod Butter X Golden Eyed Wax,	35	14	18 23	7
16	Golden Eyed Wax X Blue Pod Butter,	37	20	66 90	22
352	Brittle Wax X Blue Pod Butter,	5	1	5	3
343 347	Blue Pod Butter X Low Champion,	44	12	50 106	26
349	Blue Pod Butter X Warren,	1	2	–	–

cate that this pigment is anthocyan. In order to distinguish this from the other series it is called the red series.

The other class of pigments encountered in this work shows itself in the various shades of yellow, coffee brown and black seen in Giant Stringless, Burpee Stringless and all the Black Wax varieties. This pigment does not fade in the field, and seems only slightly soluble, or possibly insoluble, in water, but dissolves in alcohol and alkalies. Not enough work has been done with it to determine its identity, and this series of colors is referred to in this paper as the yellow-black series.

The variety Blue Pod Butter is, as previously explained, different from most other varieties in seed coat color and in other characters as well. The flower is deeper colored than any other variety and the whole plant deeply tinged with purple. The seed is of ecru or buff color, not seen in other self-colored varieties except Bountiful, which is similar. This buff color is of the same appearance as the ground color in all mottled beans.

In Table XI. are shown the results of crosses of Blue Pod Butter with other varieties of various solid colors. In all these crosses the F_1 generation shows no self-colored buff beans, but all are mottled. In F_2 we get a proportion of 1 buff or B bean to 3 of various other colors. In all cases the extracted buff beans have bred true to seed color, and also they carry the deeply colored flowers and purplish foliage of Blue Pod Butter. Of the beans shown in the column headed "various other colors" in F_2, one-fourth are of solid color and yield only solid colored beans in F_3 and F_4, while three-fourths are mottled and break up in F_3 in the same manner as do the F_1 plants. In no case has a solid colored bean yielded a buff bean like those borne by Blue Pod Butter. In Table XII. are shown crosses of Blue Pod Butter with mottled beans. Their behavior is similar to the crosses shown in Table XI., except that homozygous mottled beans

TABLE XII. — *Crosses of Blue Pod Butter with Mottled Varieties.*

Cross No.	Parent Varieties.	F_2.		F_3 and F_4 (Various Colored Parents only).	
		Various Other Colors.	B.	Various Other Colors.	B.
23	Blue Pod Butter X Red Valentine, . .	23	7	26 15	17
29	Blue Pod Butter X Warwick, ...	39	10	106 230	45
30	Warwick X Blue Pod Butter, ...	105	51	16 92	3
19	Blue Pod Butter X Mohawk, ...	9	1	14 52	6
20	Mohawk X Blue Pod Butter, ...	7	4	– 16	–
27	Blue Pod Butter X Wardwell, ...	5	4	130 7	27
28	Wardwell X Blue Pod Butter, ...	33	10	87 103	32

appear. These facts suggest that Blue Pod Butter lacks some factor possessed by the other varieties, and, furthermore, that it is associated with a mottling factor. We have called this factor M. We have already adopted the explanation of the phenomenon of mottling by assuming a formula for Blue Pod Butter of PTYz, — that is, Blue Pod Butter lacks one of the mottling factors, Z, while the other varieties shown in Table XI. have this factor Z. Blue Pod Butter, then, lacks both Z and M, while all the other varieties carry these factors. We can then express the constitution of Blue Pod Butter by the formula PTYzmo, and Burpee Stringless, for example, by PTyZMO, and the evidence is that Z and M are always associated, or that we have another case of apparently perfect gametic coupling. The varieties other than Blue Pod Butter must possess additional determining factors for the various colors exhibited. These will be dealt with later.

It has been said that we have two series of pigments in beans, — one bearing the red series, evidently anthocyan, and the other what we have called the yellow-black series. The crosses given in Table XI., excepting 343, 347 and 349, are of the latter nature, while these two crosses and three in Table XII. are crosses with varieties exhibiting colors of the red series. These behave like those given in the previous table so far as the relation of their colors to the B of Blue Pod Butter is concerned.

If we assume that it is the factor just discussed that is the determining element for the class of pigment borne, and assume, further, that there are two of these pigment modifiers, one of which, M, brings about the formation of the yellow-black pigments, and the other, which we may call M′, the formation of those of the red or anthocyan series, we have a theory that seems to explain the facts already presented and others shown later as well.

The production of a totally pigmented bean, then, rests on the presence of several factors. First, we must have P, in the absence of which we have a white bean; second, T, in the absence of which the bean has an eye; third, the presence of M or M′, the former causing beans of the yellow-black series, and the latter, pigment of the red series. If neither or only one of the mottling factors Y and Z are present the bean is self-colored, while if both are present a mottled bean results. If P and T are present and M and M′ absent, the bean is buff-colored, shown in Blue Pod Butter and the lighter shades in mottled beans. All colored varieties used in these experiments carry Y or Z or both; and the factor M or M′ or both are, when present, always associated with the factor Z.

The Behavior of the Yellow-Black Determiners.

When the factors P, T and M are present, a buff or ecru colored bean is produced. The presence of certain additional factors modifies this to the various colors of the yellow-black series. These colors are black, designated by G; coffee brown, designated by F; yellow, designated by C; and a possible light brown or olive brown, designated by H. The first-named color, G, is found in all black wax beans; the second, F, in Burpee Stringless; and the third, C, in Giant Stringless and Golden Eyed Wax. The color H is of a somewhat uncertain nature and our records are doubtless somewhat confused. It is probable that more than one character has been recorded as H. There is reason to believe that additional determiners of this series may exist, but our data are too fragmentary to afford a basis for any positive assertions. In Table XIII. are shown the results of crossing several varieties carrying yellow-brown determiners. Golden Eyed Wax X Giant Stringless yields only yellow beans like the parental varieties. In cross 50, a yellow (C) by coffee brown (F), we get apparently a simple monohybrid, the two varieties differing in that only Burpee Stringless possesses the determiner F. In all crosses involving Challenge Black Wax the F_1 seeds were black. In cross 81 Challenge Black Wax must carry G and F, for coffee brown beans like those of Burpee Stringless were extracted in F_2 and later generations. It probably carries also the yellow determiner C, for no beans lacking all three determiners appeared. In the F_2 generation the proportions should be 12:3:1, assuming that F is epistatic to C and G epistatic to F. The proportions on record are 34:2:16. There is reason to believe that some of the plants recorded as C were really F. The progeny of one C plant were mostly F. Usually it is not difficult to distinguish the two colors, but in this case it is probable that some errors were made. In crosses 43 and 44 we probably have a monohybrid, the Challenge Black Wax carrying the determiner G which is lacking in Burpee Stringless. Both carry the F and C determiners.

TABLE XIII. — *Crosses of Varieties carrying Yellow-brown Determiners.*

Cross No.	Parent Varieties.	F_1.	F_2.			F_3 and F_4.					
						G Parents.			F Parents.		C Parents.
			G.	F.	C.	G.	F.	C.	F.	C.	C.
190	Golden Eyed Wax (C) X Giant Stringless (C).	C	–	–	all	–	–	–	–	–	–
50	Golden Eyed Wax (C) X Burpee Stringless (F).	F	–	24	9	–	–	–	44 156	23	– 71
81	Challenge Black Wax (G) X Golden Eyed Wax (C).	G	34	2	16	5 22 14	3 6	3 8	21	7	–
43	Burpee Stringless (F) X Challenge Black Wax (G).	G	84	14	–	51 124	17	–	86	–	–
44	Challenge Black Wax (G) X Burpee Stringless (F).	G	55	17	–	180 101	63	–	57	–	–

Following the notation used, the formulæ for these varieties seem to be as follows: —

Golden Eyed Wax, ...	PtyZMm'OgfC
Giant Stringless, ...	PTyZMm'OgfC
Burpee Stringless, ...	PTyZMm'OgFC
Challenge Black Wax, ...	PTyZMm'OGFC

In Table XIV. are shown the results of crossing Burpee Stringless and Golden Eyed Wax with two other black wax varieties, — Prolific Black Wax and Currie. These crosses differ from those shown in the preceding table in that two new colors designated as H and B make their appearance in relatively small numbers.

Burpee Stringless carries the yellow-black modifier M and the determiners F for coffee brown, and C for yellow. Prolific Black Wax probably carries the F and possibly C, though other crosses of this variety seem to show that it lacks C, in which case its non-appearance here may be explained by the small numbers involved. It also carries the black determiner G and possibly another one, H, for olive brown, though the behavior of this color is not at all well understood.

In other crosses of this table buff-colored beans (B) appear. According to our hypothesis this can occur only when the modifier M is absent, or, if present, only when all determiners are absent. In these varieties M is present, therefore they must carry no determiner in common. Golden Eyed Wax carries the determiner C, and this must be absent in the varieties Currie and Prolific Black Wax. The absence of B beans from the F_2 generation may easily be due to the small number involved.

In one cross of Golden Eyed Wax with Currie, H beans appear, while in the other none are recorded. This may be due to the absence of a determiner for H in the strain of Currie involved. As elsewhere stated the behavior of the type recorded as H is uncertain and not well understood. The data presented in Table XIV. indicate the formulæ for Currie of PTyZMm'OGFc, with the possible additional determiner H, and for Prolific Black Wax, of PTyZMm'GFc and possibly the H in addition. The latter may carry also the determiner C, preventing the appearance of buff beans, but as other crosses indicate that it does not carry C, it is regarded as more probable that the absence of B beans is due to the small numbers involved.

In Table XV. are shown the results of the crosses of Blue Pod Butter with Burpee Stringless (coffee brown), and with two yellow seeded sorts. All these crosses but one give black mottled beans in F_1. While none of the mottled beans breed true in later generations, as has been already explained, there have been many cases where solid black beans have bred true. The appearance of these black beans is explained on the hypothesis that Blue Pod Butter carries the black determiner G, but does not have the yellow-black modifier M, and the lack of this prevents the G determiner from acting. On crossing with a variety carrying M, the G takes effect, producing a black or black mottled bean. In cross 16*a* no black beans appear. It is probable that another strain of Blue Pod Butter which lacked the G determiner was used in this cross. It must have carried the determiner F, for F is always epistatic to C, and could not be carried by Golden Eyed Wax. No B beans appear in F_2, owing, doubtless, to the small numbers, for they do come out in later generations as extractives from F parents, and some of them breed true.

TABLE XIV. — *Crosses of Varieties carrying Yellow-black Determiners.*

Cross No.	PARENT VARIETIES.	F_1.	F_2.				F_3 AND F_4.										
							G PARENTS.					F PARENTS.				C PARENTS.	
			G.	F.	C.	H.	G.	F.	C.	H.	B.	F.	C.	H.	B.	C.	B.
55	Burpee Stringless (F) X Prolific Black Wax (G), . .	G	17	2	–	5	4	1	–	–	–	9	–	–	–	–	–
							14							1			
112	Golden Eyed Wax (C) X Currie (G), ...	G	17	5	3	–	16	–	6	–	2	4	–	–	–	6	2
							9	2	5							18	
							23				8						
							36	13									
							43										
									4								
112*a*	Golden Eyed Wax (C) X Currie (G), ...	G	150	23	6	6	13	2	1	2	–	17	8	–	–	5	3
							5		7	1	2						2
							11		1								
							5			1							
							60	20									
							183										
237	Golden Eyed Wax (C) X Prolific Black Wax (G), . .	G	40	20	3	1	11	3	–	2	–	–	–	–	–	–	–
							3	1	1								
							54			10							
							16		7								
							42	18									
							44										

TABLE XV. — *Crosses of Blue Pod Butter with Brown and Yellow Beans.*

Cross No.	Parent Varieties.	F_1.	F_2.					F_3 and F_4.															
								G Parents.					F Parents.				H Parents.				C Parents.		B Parents.
			G.	F.	C.	H.	B.	G.	F.	C.	H.	B.	F.	C.	H.	B.	F.	C.	H.	B.	C.	B.	B.
1	Blue Pod Butter X Burpee Stringless.	G	122	14	24	5	56	31	10	–	–	16	22	–	8	7	–	5	10	1	47	21	20
													4	2	1				20	8	20		
								8	4	1			14	5		4			4				
								5		4			26		12		1		2	2			
								53					26	8			10			5			
													10				10						
2	Burpee Stringless X Blue Pod Butter.	G	91	10	9	4	40	3	1	–	–	2	–	–	–	–	2	–	14	11	–	–	12
								89									4			7			
																	2						
11	Blue Pod Butter X Giant Stringless,	G	6	–	2	–	1	6	–	1	–	5	–	–	–	–	–	–	–	–	23	10	–
								18		4											10		
12	Giant Stringless X Blue Pod Butter.	G	14	–	2	–	14	8	–	–	–	3	–	–	–	–	–	–	–	13	–	–	–
								7															
12a	Giant Stringless X Blue Pod Butter,	G	17	6	6	–	20	6	–	–	1	4	–	–	–	–	–	–	–	–	16	5	–
								8			2										11		
15	Blue Pod Butter X Golden Eyed Wax.	G	14	11	5	–	11	3	1	1	–	–	–	–	–	–	–	–	–	–	15	3	10
								6	6														
								1				1											
									4	2													
16	Golden Eyed Wax X Blue Pod Butter.	G	19	3	7	–	18	6	–	–	4	–	5	–	4	–	–	–	–	–	5	–	–
								12		5		2											
								11	3			6											
								9				4											
								15															
16a	Golden Eyed Wax X Blue Pod Butter.	F	–	5	1	–	–	–	–	–	–	–	25	–	–	6	–	–	–	–	–	–	42
													19										

Beans classified as H appear in F_2 in the crosses with Burpee Stringless only, but they do appear scatteringly in later generations of most of the other crosses. Too small numbers are involved to determine its nature and relations. It is not always easy to separate the several colors F, C and H in making field observations. These colors seem to develop in the ripening beans somewhat in order of their epistasis, the olive H first, and so on up to the coffee brown, and even black, provided determiners for these higher colors are present. The fact that several selfed plants recorded as H gave rise to offspring made up partially or wholly of F beans in crosses 1 and 2 raises the suspicion that these parent plants really carried the determiner F, but for some reason failed to develop their true color. Possibly the weakening effect of covering the plant, which has been already discussed, may have had this effect.

The yellow color C is more positively determined in the field, and the records seem clear. Extracted C beans either breed true or yield B beans in the proportions 3C:1B. According to our hypothesis there might be a 9:7 proportion in cases like this when the heterozygote is a hybrid, as Mc mC. Such a heterozygote would be yellow, and would yield 9 yellow to 7 buff. No such proportion is approached among the offspring of C parents, but in the other columns are shown a few cases that approach such a proportion. Their number is too few to be sure whether they are 9:7 or 3:1 proportions. The total numbers of such offspring in the table are 172 G, F, H and C beans to 73 buff. This is a considerable excess of buff beans, and supports the idea that some of these proportions are really 9:7. If such cases do occur the buff beans would be of three kinds, some lacking the modifier M, some the determiner and some lacking both. This raises the question whether these can be distinguished from each other. While this cannot be answered positively, we are quite sure that more than one kind of buff beans does appear. Some further evidence will be presented on this point in connection with a discussion of the relations between seed coat and flower colors.

In Table IV. are shown the results of crossing self-colored varieties where mottled progeny resulted. This showed equal numbers of self-colored and mottled beans, in harmony with the hypothesis of Emerson. In Table XVI. are shown those crosses which involve Blue Pod Butter and black wax varieties, separating the self-colored beans into black and buff. These appear in approximately equal numbers and both breed true. It was early observed that buff beans generally bred true in all crosses, and comparatively few were planted. This accounts for the small numbers given in the right-hand column of the table. Our records show some half dozen plants scattered through the several crosses that were called smoky black or brown. None of them were self-fertilized, and it is impossible to say whether they represented types that appear in very small proportion, whether they were mutations, or whether they were the result of environmental conditions. We are inclined to attribute them to the last-named influence. If the constitution of Blue Pod Butter is represented by the formula PTYzmG, and that of the black wax varieties by PTyZMG, either or both having possible additional hypostatic determiners, we have in effect a simple monohybrid based on the presence or absence of the modifier M with its accompanying mottling factor Z. This gives a proportion 3M:1m. Two of the plants carrying the modifier are heterozygous and mottled, while one is homozygous and is solid black. Inasmuch as Y and Z are confined to different gametes, according to Emerson's hypothesis, no zygote PTyzm is possible. Thus we have the theoretical proportion 1 black, 2 mottled, 1 buff, which is borne out by the facts presented in the table.

TABLE XVI. — *Crosses of Blue Pod Butter with Black Wax Varieties.*

Cross No.	Parent Varieties.	F_1.	F_2.			F_3 and F_4.				
						GBO Parents.			G Parents.	B Parents.
			G.	GBO.	B.	G.	GBO.	B.	G.	B.
3	Blue Pod Butter X Challenge Black Wax.	GBO	21	36	18	6	25	29	53	-
4	Challenge Black Wax X Blue Pod Butter.	GBO	64	110	53	11	29	14	71	8
5	Blue Pod Butter X Currie, .	GBO	5	20	7	2	2	1	37	-
6	Currie X Blue Pod Butter, .	GBO	23	33	13	28	64	26	134	-
9	Blue Pod Butter X German Black Wax.	GBO	6	4	6	-	-	-	21	-
10	German Black Wax X Blue Pod Butter.	GBO	15	47	12	11	25	15	23	-
21	Blue Pod Butter X Prolific Black Wax.	GBO	48	73	48	27	52	26	253	43
22	Prolific Black Wax X Blue Pod Butter.	GBO	31	70	34	45	81	46	68	70

The variety Bountiful has seeds that bear some resemblance to those of Blue Pod Butter. They have been recorded by the same symbol, B. The flowers are pink instead of crimson, and the plants do not show the marked purplish tinge. It has been used in crossing to a limited extent only. In Table XVII. are tabulated the results of crosses with two black wax varieties. From the results of other crosses we have assigned to the black wax varieties the black, brown and, in some cases at least, the yellow determiner. In these crosses with Bountiful all these colors appear as well as the H color, the behavior of which we do not clearly understand. This indicates that Bountiful does not possess any of these determiners. Buff-colored beans appear only in small numbers, indicating that it does not lack the modifier M. If we assign to Bountiful the formula PTyZMgfc, and to the black wax varieties the formula PTyZMGFC, the results of crossing would be in harmony with the limited data shown in Table XVII.

TABLE XVII. — *Crosses of Bountiful with Black Wax Varieties.*

Cross No.	Parent Varieties.	F_1.	F_2.					F_3 and F_4.													
								G Parents.					F Parents.				H Parents.				B Parents.
			G.	F.	C.	H.	B.	G.	F.	C.	H.	B.	F.	C.	H.	B.	F.	C.	H.	B.	B.
350	Bountiful (B) X German Black Wax (G), .	G	14	5	1	2	–	21	–	–	–	–	5	2	1	–	–	1	3	1	–
354	German Black Wax (G) X Bountiful (B), .	G	6	3	1	–	–	7 7 2	– 3 1	7 5	–	4	1 1 6	1	1 1	–	–	–	–	–	–
351	Bountiful (B) X Prolific Black Wax (G), . .	G	7	–	–	1	1	23 12 16 16	–	–	3 8	1	–	–	–	–	–	–	–	1	6
362	Prolific Black Wax (G) X Bountiful (B), . .	G	2	–	–	1	2	29	–	–	–	–	–	–	–	–	8	–	–	–	–

The Behavior of the Determiners of the Red Series.

According to the hypothesis already presented (see page 82), some varieties carry a modifier which gives rise to a series of colors different from the yellow-black series just considered. Only two members of this series have been clearly recognized in this work, — one a dark or purplish red designated by E, seen in Mohawk, and a lighter red seen in Red Valentine which we have called D. Beans of the darker shade are changed to the lighter on immersing in acid solutions, and a reversal of this is seen on treatment with a solution of potassium hydrate. The darker alkaline color seems to be dominant, and the limited data presented in Table XVIII. indicate that crosses of these determiners behave as a simple monohybrid. As no light red beans appear in cross 215, both Golden Carmine and Mohawk must carry the factor E. No signs of a buff-colored bean have appeared in cross 258, therefore it is assumed that both Red Valentine and Keeney Rustless carry the factor D, while the latter variety carries the factor for the purplish red determiner E, which is lacking in Red Valentine.

Table XVIII. — *Crosses of Light Red with Dark Red Varieties.*

Cross No.	Parent Varieties.	F_1.	F_2.		F_3 and F_4.		
					E Parents.		D Parents.
			E.	D.	E.	D.	D.
215	Golden Carmine X Mohawk, .	E	2	–	81	–	–
258	Red Valentine X Keeney Rustless,	–	26	9	16 26	7	62

The relations of Blue Pod Butter and the several varieties of the yellow-black series have already been discussed. Table XIX. shows in a similar way the relations of Blue Pod Butter and varieties of the red series. The hypothesis of the "red" modifier M' as necessary for the expression of these colors has already been advanced. Upon this hypothesis and that of the two determiners E and D the facts shown in the table can be fairly well explained, though a few cases are rather difficult of explanation. Blue Pod Butter carries the determiner E but lacks the modifier M'. When this is supplied by crossing with Red Valentine, Low Champion or Warwick, dark red E beans appear in dominant proportions. For some reason the F_1 beans in the Warwick crosses appear to have been lighter in color, and were recorded as light red, or D. In later generations undoubted dark red beans appear. Whether this is due to some environmental influence or to an unknown genetic influence cannot be stated. This has been recorded in two different years, and can hardly be an error of observation.

Table XIX. — *Crosses of Blue Pod Butter with Varieties of the Red Series.*

Cross No.	Parent Varieties.	F_1.	F_2.			F_3 and F_4.				
						E Parents.			D Parents.	
			E.	D.	B.	E.	D.	B.	D.	B.
23	Blue Pod Butter (B) X Red Valentine (D).	Dark red	16	7	7	26	–	17	–	–
						15				
343 347	Blue Pod Butter (B) X Low Champion (D).	Dark red	30	14	12	7	4	7	30	16
						9		3	11	
						17	7			
						57				
29	Blue Pod Butter (B) X Warwick (D),	Light red	26	13	10	17	5	7	63	29
						9		3	64	
						98	29			
						39				
30	Warwick (D) X Blue Pod Butter (B),	Light red	75	30	51	44	16	–	28	–
19	Blue Pod Butter (B) X Mohawk (E),	Dark red	8	1	1	10	4	6	36	–
						16				
20	Mohawk (E) X Blue Pod Butter (B),	Dark red	6	1	4	–	–	–	–	–
27	Blue Pod Butter (B) X Wardwell (E),	Dark red	5	–	4	34	7	8	11	1
						78		18		
						4	3			
28	Wardwell (E) X Blue Pod Butter (B),	Dark red	25	8	10	28	13	21	39	–
						46		11		
						49	16			
						43				

The Interrelations of the Yellow-black and Red Series.

All the varieties showing pigments of the red series are mottled beans with the exception of Warren, and Warren has not been crossed with varieties of the yellow-black series. Therefore all crosses between red and yellow-black varieties shown in Table XX. are mottled in the first generation. Owing to this fact the colors of both series may usually be seen on examination of the F_1 beans. It is possible to separate the beans of the F_2 generation into three classes, as shown in the table. The yellow-brown beans are partly self-colored and partly mottled, showing only yellow-brown or black, as the case may be. A larger number are mottled, showing these colors and also light or dark red, or both. A third class shows only red, and these are always mottled. No solid red bean of any shade of color has ever appeared from the crosses shown in Table XX. All plants listed in the yellow-black column breed true to these colors, and the same is true of those belonging to the class of red beans. Those in the middle column break up exactly like the F_1 generation. These facts are shown in the columns under F_3 and F_4.

In crosses 198, 119, 191, 194, 115 and 52, buff beans appear in small numbers in F_3 and F_4, but none have been observed in the F_2 generation. In the other crosses more have been observed. If the parent varieties possess a determiner in common the chances of a buff bean appearing would be small, and this may explain their absence. Probably if the numbers involved were larger they would appear in many crosses where they are not shown.

According to the hypotheses already advanced, these crosses involve varieties whose constitution may be expressed by PYZmM′ X PyZMm′, each variety possessing one or more determiners in addition. The mottled beans of the yellow-black series, appearing from these crosses, are the heterozygotes lacking the determiners E and D. No such beans have bred true.

TABLE XX. — *Crosses of Varieties of the Yellow-black with the Red Series.*

Cross No.	Parent Varieties.	F₂.			F₃ and F₄.				
					y-b+r Parents.			y-b Parents.	r Parents.
		y-b.	y-b+r.	r.	y-b.	y-b+r.	r.	y-b.	r. .
240	Golden Eyed Wax (y-b) X Red Valentine (r).	–	–	–	12	16	16	80	–
239	Red Valentine (r) X Golden Eyed Wax (y-b).	12	36	15	8	12	6	–	–
198	Red Valentine (r) X Giant Stringless (y-b).	5	20	10	18	41	4	41	–
57	Burpee Stringless (y-b) X Red Valentine (r).	–	–	–	20	11	7	25	–
58	Red Valentine (r) X Burpee Stringless (y-b).	20	55	8	25	44	16	102	72
					12		29		
					13	17			
288	Red Valentine (r) X Prolific Black Wax (y-b).	10	15	5	10	9	10	202	15
119	Currie (y-b) X Red Valentine (r).	21	36	17	11	–	11	–	76
					3	5			
95	Challenge Black Wax (y-b) X Warwick (r).	13	14	2	3	7	2	–	–
201	Giant Stringless (y-b) X Wardwell (r).	20	33	11	23	32	8	117	26
					11	14			
						13	6		
					7				
191	Giant Stringless (y-b) X Keeney Rustless (r).	1	3	1	9	18	9	36	5
193	Giant Stringless (y-b) X Mohawk (r).	2	6	6	17	4	1	–	–
194	Mohawk (r) X Giant Stringless (y-b).	2	5	8	27	49	13	–	37
115	Currie (y-b) X Mohawk (r), .	49	90	32	11	10	6	85	15
					16		6		
					15	10			
116	Mohawk (r) X Currie (y-b), .	8	19	9	2	11	2	24	8
52	Keeney Rustless (r) X Burpee Stringless (y-b).	3	6	2	7	11	3	30	25

A detailed study of the records of the progeny of crosses like those shown in Table XX., giving consideration to the manifestation of the various pigments, leads to conclusions already advanced in the discussion of the crosses belonging within each series (page 84). Some five or six varieties of red mottled beans have been crossed with a similar number belonging to the yellow-black series. The results do not lend themselves readily to tabular presentation, therefore they are dealt with in a text discussion. These facts are in addition to those shown in Table XX.

Red Valentine crossed with Golden Eyed Wax yields buff beans in small numbers, indicating that these parents possess no determiners in common. One plant with red mottled beans yielded in the next generation red mottled and buff beans in the proportion of 3:1, indicating that the parent plant was heterozygous for the factors M and D. Red Valentine X Giant Stringless gives results of the same nature, and they indicate the same constitution as that of Golden Eyed Wax. In one cross of these two varieties, dark red and even black beans appeared. This is so contrary to the usual experience that it is thought they are due to accidental crossing in the field, or some other accident of similar nature.

In crosses of Red Valentine with Burpee Stringless we have coffee brown, yellow and light red mottled beans, as would be expected from the formulæ already advanced. Buff beans also appear in small numbers, indicating that these two varieties have no determiner in common. Dark red mottled beans appear in numbers greater than those of light red mottled beans, and so distributed as to make it doubtful if they are the result of accident. Their presence can be explained on the supposition that Burpee Stringless carries the determiner E. Small numbers of olive-brown, or H, beans appear as in other similar crosses. The constitution indicated for Burpee Stringless is PTyZMm'FCEd, which is in harmony with the one previously advanced.

Dark red mottled beans have been extracted from crosses of Red Valentine with Prolific Black Wax, indicating that Prolific Black Wax carries the alkaline determiner E. This type, self-fertilized, yields dark red mottled and light red mottled beans in the proportion 25:12, probably a simple 3:1 ratio. Buff beans also appear in small numbers, indicating that these two sorts have no determiner in common. Coffee brown, or F, beans appear in considerable numbers, and when selfed sometimes breed true, or may yield yellow (C), buff (B) and olive-brown (H) beans in proportions subordinate to the coffee brown. In this as in other crosses involving Red Valentine, the parent type, light red mottled, always breeds true when extracted.

Warwick has a coat color apparently very similar to or identical with Red Valentine. The blossom color is light pink, while the usual strains of Red Valentine are white. This indicates a different pigmentation for the two varieties, which may or may not affect the color of the seed coat. When crossed with Challenge Black Wax, Warwick gives in the F_1 generation a mottled bean showing black and red similar to those where Red Valentine is involved. In later generations there is a greater complexity among the mottled beans. Coffee-brown and yellow beans are extracted, also the buff, or B beans, all in rather small numbers. These solid-colored beans all breed true or yield other hypostatic or recessive colors in comparatively simple proportions. Among the mottled beans various shades of black, violet, brown, red and yellow may be seen, and in addition the buff color always showing in mottled beans. Beans of these complex colors segregate into self-colored beans or mottled beans of less complex natures. We have observed no case where a mottled bean showing colors of both the red and yellow-black series has bred true. From crosses similar to the one just discussed we have extracted black mottled beans similar to Refugee that have bred true, though not in large numbers.

Mohawk has a seed coat color somewhat similar to Red Valentine and Warwick, but the red color is darker and is changed to a bright red by acid solutions. It is assumed to carry the alkaline modifier E. When crossed with Giant Stringless it yields in F_2 numerous plants with coffee-brown beans, indicating that Mohawk carries the determiner F. When crossed with Burpee Stringless no yellow beans appear, for both these varieties carry F, and the hypostatic yellow color cannot appear.

Keeney Rustless crossed with Burpee Stringless yields many black beans. This may be explained by assuming that Keeney Rustless carries the black determiner G but not the modifier M, which prevents the appearance of the black color. It does carry M′ and E, and is therefore a dark red bean. Burpee Stringless supplies the modifier M which with the determiner G brings forth the black color. The cross Keeney Rustless X Burpee Stringless may be expressed by PmM′GfcED X PMm′gFC. It is probable that Burpee Stringless carries an E also. Buff-colored beans appear in this cross, indicating a lack of common determiners.

Wardwell crossed with Giant Stringless and Burpee Stringless yields progenies similar to those resulting from a cross of the latter two varieties with Mohawk so far as pigments are concerned. Both Mohawk and Wardwell carry the determiner F, but it is not expressed owing to the lack of the modifier M. When this is supplied by Giant Stringless or Burpee Stringless coffee-brown flecks appear in the mottled beans, and various types of mottled beans and both mottled and self-colored beans of the yellow-black series may be isolated.

Crosses involving Creaseback.

In Table VI. were presented the manifestation of color patterns in crosses of Creaseback with Blue Pod Butter and Challenge Black Wax. In Table XXI. are shown the same crosses, giving the proportion of plants exhibiting the various seed coat pigments involved. In the discussion of Table VI. (page 74) it was brought out that Creaseback must carry the determiner G, and its formula according to the hypotheses followed is pyZMG. As soon as the factor for pigment is introduced by Blue Pod Butter, which may be assumed to have here the formula PYzmG, black beans appear making up all the F_1 generation, and in F_2 there follows what is probably a 9:3:4 proportion with the buff of Blue Pod Butter and white. The exact proportion is 9.21:2.55:4.31 when all lots showing the three colors are combined. Where black seed parent plants show only buff or white progeny besides black, and where buff seed parent plants yield white seeded progeny, there is evidently a simple 3:1 proportion.

In cross 97, Challenge Black Wax X Creaseback, there is evidently a simple 3:1 proportion based on the presence or absence of the factor for pigmentation. Cross 97 as tabulated is derived in part from a cross made in 1909 and in part from a cross made in 1911, which exhibited similar behavior. In the 1911 cross there were four F_1 plants, two of which gave the progeny just referred to, and the other two gave the progeny shown in cross 97*a*. Why these show such a different proportion we do not know, for 97*a* must have been a successful cross, as proved by the appearance of pole beans in normal proportions. It may be that the pollen grains were not of the same constitution, or possibly stray pollen grains carrying only black were involved in the F_1 generation. The facts are here presented in the hope that they may be suggestive to some other investigator.

TABLE XXI. — *Crosses involving Creaseback.*

Cross No.	Parent Varieties.	F_1.	F_2.			F_3 and F_4.				
						G Parents.			B Parents.	
			G.	B.	A.	G.	B.	A.	B.	A.
31	Blue Pod Butter X Creaseback, .	G	111	33	65	155	46	67	61	21
						113		33		
						131	34			
						119				
32	Creaseback X Blue Pod Butter, .	G	55	13	33	66	14	16	–	–
						75		22		
						103	31			
						65				
97	Challenge Black Wax X Creaseback,	G	295	–	79	269	–	75	–	–
						136				
97*a*	Challenge Black Wax X Creaseback,	G	101	–	1	29	–	2	–	–
						60				

Crosses of other varieties with Creaseback are not shown in the table because the results were complicated and somewhat uncertain. With Golden Eyed Wax the F_1 generation gave only black beans, and in F_2, 10 black to 3 white. In F_3 and F_4 there appeared also coffee-brown (F) and yellow (C) seeded plants in moderate numbers. One coffee-brown plant bred true in the 9 progeny grown.

When crossed with Warwick the results were complicated beyond hope of comprehension. In the cross Creaseback X Warwick the F_1 generation is recorded as black with faint signs of mottling, while in the reciprocal, which may have involved a different strain of the parent varieties, the F_1 beans were distinctly mottled, showing many distinct shades of pigments. Apparently about all the pigments of both the red and yellow-black series were involved.

The behavior of the pigments in these reciprocal crosses does afford some further evidence bearing on the hypothesis of a factor discussed on page 75 and there called X. One strain of Warwick X Creaseback gives the expected number of white beans, the ratio being 24 self-colored, 5 mottled and 9 white. Another strain yields no white beans but gives 30 self-colored and 7 mottled in both cases, approximately four times as many self-colored as mottled. If there is a factor X in Creaseback which inhibits the expression of mottling as previously suggested, the following gametes should be formed: PYZX, pYZX, PyZX, pyZX, PYZx, pYZx, PyZx, pyZx. The zygotes formed would yield 9 mottled without X, 27 with X; 12 self-colored and 16 white. The 27 "mottled" beans with X do not show mottling, making a total of 39 self-colored, 9 mottled and 16 white, or nearly four times as many self-colored as mottled. Of the mottled beans 6 should show colors of both series, and 3 those of the red series only, which are the actual numbers shown in the F_2 generation of this cross.

Crosses involving Davis Wax.

As has already been shown, Davis Wax, a non-pigmented bean, carries factors for light mottling which appear as soon as pigment is supplied. When crossed with Blue Pod Butter the F_1 generation is light mottled, like beans of the Horticultural group. In F_2 there are produced light mottled, buff and white beans in the proportion, presumably, of 9:3:4. In later generations these behave as shown in Table XXII. It is possible to derive from this cross light mottled races that breed true as well as the parent types, as is shown in the table. No black beans appear, as the modifier M is not present.

TABLE XXII. — *Crosses involving Davis Wax.*

Cross No.	PARENT VARIETIES.	F_1.	F_2.			F_3 AND F_4 (BEP PARENTS).		
			BEP.	B.	A.	BEP.	B.	A.
7	Blue Pod Butter X Davis Wax, .	BEP	14	3	6	50	0	18
8	Davis Wax X Blue Pod Butter, .	BEP	38	16	22	17	10	12
						49		16
						8	3	
						53		

Among these light mottled progeny there appear some plants that produce what seem to be bud sports, in which the darker reddish color predominates over the surface of the bean. These may appear as single pods or as branches bearing several pods, and rarely a portion only of the beans in a single pod is affected. If these dark mottled beans are planted they breed true to seed coat color, while the plants with light mottled seed may breed true in this character, or may give rise to plants bearing bud sports as before. Limited observations suggest that these sporting plants exist in definite proportions. The fact that such plants have appeared so often in the breeding work here reported, and that dark mottled beans are frequently seen in seed of varieties of the Horticultural type offered for sale, suggests that this peculiarity of bud sporting is a frequent and possibly a constant character of beans of this class. At any rate, we have here a peculiarity which would doubtless yield interesting results on further and more specific investigation.

Reciprocal crosses of Challenge Black Wax and Davis Wax yielded complicated progenies. Dark mottled beans appear because the former variety carries the factor O for dark mottling, which acts with YZ from Davis Wax to bring about this result. Challenge Black Wax carries the modifier M, and Davis Wax brings in M′, so that we get beans of both the yellow-black and red series. Owing to the complicated nature of the progeny of this cross it is not shown in tabular form.

Crosses involving White Marrow.

The only other white variety that has been used at all extensively is White Marrow. The color pattern factors are rather complex, and the pigment factors much more so. Owing to this the crosses of White Marrow with the several varieties used will be taken up one by one. Apparently White Marrow carries several pigment modifiers and determiners in a latent condition, owing to the absence of the pigmentation factor P. When it is crossed with another variety carrying P, and perhaps several additional modifiers and determiners, we have very many classes of beans which are extremely difficult to segregate.

Crosses of White Marrow and Blue Pod Butter. — Three crosses of these varieties have been made, including reciprocals. As previously indicated (page 73), the F_1 beans have light red (D) stripes and splashes on the usual buff (B) ground color. In the next generation these split up, showing, in addition to the two colors mentioned and the parent forms, considerable numbers of coffee-brown (F) and yellow (C) beans. No black beans have appeared in this cross, a fact that may be explained on the hypothesis that the particular strain of Blue Pod Butter used lacked the factor G.

We have been led to conclude that Blue Pod Butter lacked both modifiers M and M′. The appearance of both series of colors in the progeny of this cross leads to the conclusion that White Marrow carries both modifiers in an inactive state, owing to the lack of the factor P. When both are present the M′ is epistatic to M, and the beans are classified as of the red series.

Beans showing the dark red color have yielded in some cases only the parent color (E), and in other cases various combinations of dark red (E), light red (D), yellow (C), buff (B) and white, but we have no record of coffee-brown beans (F) from this parentage, though they do appear in small numbers from light red (D) parents. Yellow (C) parent plants yield progeny of similar color, and, in addition, buff (B) or white or both in subordinate numbers. In a few cases our records show light red (D) beans in small numbers, which occurrences are difficult to explain. They are rather too frequent to be mere accidents. Further investigation should lead to interesting results.

Crosses of White Marrow with Golden Eyed Wax. — The progeny of this cross are less complicated than others having White Marrow in the parentage. The first generation beans, being mottled, show both yellow and red splashes. Those of the F_2 generation, showing only yellow either in solid color or mottling, either breed true or yield white beans in the expected ratio. Among some three hundred plants the records show two buff (B) seeded plants. These are probably accidental strangers, yet they may be a definite class occurring in small numbers; if so, no explanation of their occurrence can be presented.

Crosses of White Marrow with Burpee Stringless. — Other crosses have shown that Burpee Stringless has a constitution similar to Golden Eyed Wax, with the addition of the determiner F, making the bean coffee brown. The beans of the F_1 generation were of a yellow-olive mottled color. In the next generation a variety of colors appeared among the mottled beans, — coffee brown, yellow, olive, chocolate brown and red. In later generations these differentiated clearly into the coffee brown of Burpee Stringless, yellow (C), light red (D), buff (B) and white. Self-colored coffee-brown seeds have given all brown, brown and yellow, brown and white, and mixed progeny including all three types. Light red, light mottled seeds have bred true, and have yielded white seeded plants in the usual proportion of 3:1.

Crosses of White Marrow with German Black Wax. — The results of this cross are similar to the previous one with the addition of the epistatic black (G). There is the same confusion of colors in the F_1 generation, but on further segregation they separate into black, coffee brown, yellow and white. The light red also appears and apparently dark red (E) also, though in small numbers.

We have no case where a parent plant of this color has been bred. One yellow seeded plant, being selfed, yielded yellow and white in a 3:1 proportion, and one solid black of the F_2 generation yielded a mixture of black and coffee brown.

Crosses of White Marrow with Red Valentine. — This cross differs from those just considered in that Red Valentine belongs to the red series. There are red, black or brown beans appearing, but yellow does appear in many of the mottled beans. One plant of mostly solid yellow beans produced a progeny of yellow and light red mottled beans, the former in larger numbers. There is a tendency to produce the dark mottled bud sports referred to on page 98. There are other complications in this cross, some of which can be explained only on the supposition that the White Marrow plant used as a parent was heterozygous in its nature. This might well be, for so long as the factor P is absent the pigment modifiers and determiners might be interchanged without the external appearance being changed.

The Genetic Constitution of the Varieties used.

In the following table is given the genetic constitution as indicated by the investigations here reported. It is not asserted that these are correct in all cases, even should the general hypotheses here presented prove sound. Moreover, there are doubtless in a given variety different strains of indistinguishable external appearances, especially among the non-pigmented varieties.

Blue Pod Butter,	P T Y z m m′ o G f c H E d P T Y z m m′ o G F c H E d P T Y z m m′ o g F c H E D
Bountiful,	P t Y Z m M′ O g F C H E D
Burpee Stringless,	P T y Z M m′ O g F C h E d
Challenge Black Wax,	P T y Z M m′ O G F C h E D
Creaseback,	p T Y Z M m′ O X G p T y Z M m′ o X G F C H E D
Currie,	P T y Z M m′ O G F c H P T y Z M m′ O G f C H E D P T y Z M m′ O G f C H e D
Davis Wax,	p T Y Z m M′ o g e d
German Black Wax,	P T y Z M m′ O G F C H E D
Giant Stringless,	P T y Z M m′ O g f C h E d
Golden Carmine,	P T Y Z m M′ o g f c h E d
Golden Eyed Wax,	P t y Z M m′ O g f C h e d
Keeney Rustless,	P t Y Z m M′ O G f c H E D
Longfellow,	P T Y Z m M′ O g f c h e D
Low Champion,	P T y Z m M′ O e D
Mohawk,	P T Y Z m M′ O g F c H E D
Prolific Black Wax,	P T y Z M m′ O G F c H E
Red Valentine,	P T Y Z m M′ O g f c h e D P T Y Z m M′ O g f c H e D P T Y Z m M′ O g f C h e D
Wardwell,	P t Y Z m M′ O g F c H E D
Warren,	P T Y z m M′ E D
Warwick,	P T Y Z m M′ O g f c H e D
White Marrow,	p T Y Z M M′ o g f C h e D p T y Z M M′ o g f C h e d p T Y z p T y Z M M′ o g f C h e D

The significance of the letters is as follows: —

P is the factor for pigmentation, without which the bean is white. Presumably this factor is the one causing the production of the basic chromogen.

T is the factor for totality of pigmentation, without which the bean is an eyed bean if P is present.

Y and Z are the factors for mottling, which are coupled in mottled varieties but may exist separately in non-mottled varieties, and if brought together in crossing give mottled beans which break up in later generations.

M and M′ are the two modifiers, M giving rise to the beans of the yellow-black series and M′ to those of the red series. They doubtless represent one of the enzymes that are believed to be necessary for the production of sap colors in plants.

O is the factor for dark mottling in mottled beans, in the absence of which we have the light mottled type of the Horticultural class, provided P, Y and Z are all present.

X represents a blackening factor found only in Creaseback.

The remaining letters of the formulæ are the determiners which in the presence of other necessary factors determine the color of the seed coat. The significance of the colors is as follows: G, black; F, coffee brown; C, yellow; E, dark red; D, light red (see page 84).

SUMMARY.

It is evident from these and other investigations that the inheritance of seed coat color in beans is very complicated, and difficult to explain fully and satisfactorily. The problems involved are interesting, and the plants convenient to handle for purposes of investigation. They provide excellent material for the fruitful investigation of Mendelian inheritance.

In this work 21 varieties have been used in making over 120 different crosses, involving more than 40,000 plants. The work continued over a period of eight years.

There are certain correlations in the pigmentation of the plant. All white or eyed beans are accompanied by white flowers; all black or black mottled beans by dark pink flowers. Mottled beans, other than black mottled beans and those of various yellow and brown colors, are usually accompanied by light pink flowers.

In a general way the crosses of pigmented and white beans show a 3:1 ratio, but there are some rather wide departures which may or may not be of genetic significance.

The inheritance of mottling may be explained by the double factor hypothesis of Emerson and Spillman. Crosses of two mottled varieties have in all cases given only mottled progeny. Crosses of mottled and self-colored varieties have yielded mottled beans in F_1, and the parent types in a 3:1 ratio in F_2. Crosses of mottled and white varieties have given mottled beans in F_1, and usually mottled, self-colored and white in a 9:3:4 proportion in F_2.

In most cases crosses of two self-colored varieties have given only self-colored progeny. The principal exceptional variety is Blue Pod Butter, which, when crossed with most self-colored varieties, yields mottled progeny none of which breed true to the mottled character. White varieties may carry the character for mottling, which can show itself only after crossing with a pigmented sort. Creaseback is peculiar in that it seems to carry factors for mottling and an additional factor causing a blackening which nearly or quite obscures the mottled pattern.

There are two types of mottling, — the dark, seen in Red Valentine and Refugee and many others, and the light, seen in varieties of the Horticultural class. The former behaves towards the latter as a simple dominant.

Apparently the factor for the dark mottling is associated with one of the mottling factors. White beans may yield light mottled beans, but none have yielded dark mottled beans.

There is evidently needed to produce a totally pigmented bean a factor for total pigmentation. If it is absent when the factor for pigmentation is present we have an eyed bean. Eye size is evidently governed by one or more factors, but these investigations do not afford definite data regarding their relations.

Pigment patterns and pigment colors are controlled by distinct factors. According to the hypothesis presented in this paper, any color shown in a bean seed is, in most cases, dependent on three or more factors. The basic factor for pigmentation may be modified into either one of two series, — one including the various yellows, browns and black; and the other, different shades of red. The third factor, called a determiner, finally determines what the color is to be. In some cases the determiners bring about the color through causing an alkaline or acid condition. Possibly in some cases the color is determined by the degree of acidity or alkalinity.

The two modifiers discovered are apparently associated with one of the mottling factors, but the determiners are free and independent, though standing often in an epistatic or hypostatic relation to one another.

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BULLETIN No. 186 NOVEMBER, 1918

MASSACHUSETTS AGRICULTURAL EXPERIMENT STATION

I

The Composition, Digestibility and Feeding Value of Alfalfa

II

The Value of Corn Bran for Milk Production

By J. B. LINDSEY and C. L. BEALS

Part I of this bulletin contains a summary of all analyses and digestion experiments made with alfalfa and red clover, including those made at this station. It contains also the results of three feeding experiments with milch cows, intending to throw light upon the value of alfalfa as an efficient source of milk protein, its effect upon the action of the kidneys in causing a milk shrinkage, and its value for milk production when fed as the entire source of roughage together with corn meal. Experiments IV and V compare alfalfa with rowen, and VI and VII were conducted to ascertain how best to combine alfalfa with other feedstuffs in making up the dairy ration. A summary of all results will be found on pages 105-107.

Part II of the bulletin describes two feeding experiments with corn bran as a component of the dairy ration. Conclusions and suggestions will be found on page 142.

Requests for bulletins should be addressed to the
Agricultural Experiment Station
Amherst, Mass.

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Publication of this Document
approved by the
Supervisor of Administration.

BULLETIN No. 186.

DEPARTMENT OF CHEMISTRY.

PART I.

THE COMPOSITION, DIGESTIBILITY AND FEEDING VALUE OF ALFALFA.

BY J. B. LINDSEY AND C. L. BEALS.

SUMMARY AND SUGGESTIONS.

1. Green alfalfa contains from 70 to 80 per cent. of water, 2 to 2.5 per cent. of ash, 2.9 to 4.7 per cent. of protein, 4.2 to 12.8 per cent. of fiber, 7.98 to 11.3 per cent. of extract or starchy matter, and not over 1 per cent. of fatty matter.

2. Alfalfa hay of good quality should average about 14 per cent. of water, and on this basis will contain some 7 to 9 per cent. of ash, 13 to 14.5 per cent. of protein,[1] 27 to 33 per cent. of fiber, 33 to 36 per cent. of starchy matter and 1.5 to 2 per cent. of fat. The earlier it is cut the less fiber and the more ash and protein it will contain.

3. Alfalfa resembles red clover quite closely in chemical composition, although it is likely to be slightly lower in protein and starchy matter. Both alfalfa and clover contain considerably more protein and less fiber and extract matter than do the cereals and grasses.

4. A complete chemical study of the different food groups composing the alfalfa has not been made. In early blossom an average of 71.1 per cent. of its total nitrogen has been found to exist as true protein, and 28.9 per cent. as non-albuminoid nitrogen. One sample has shown 10.17 per cent. in the form of amino acids, and fully 88 per cent. as true protein. In the carbohydrate group from 3.9 to 16.8 per cent. of pentosans, and as high as 4.71 per cent. of galactan, have been found.

5. Alfalfa, red clover and timothy hay contain about the same amount of digestible organic nutrients in 1 ton (950 to 970 pounds); while rowen averages 1,028 pounds, or 8 per cent. more; and gluten feed, 1,556 pounds, or 64 per cent. more.

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[1] Cut before bloom, alfalfa may contain 20 per cent. protein.

6. Comparing these several feeds, however, on the basis of net energy values, as suggested by Armsby, one finds red clover to have 13 per cent. more energy value, timothy hay and rowen 20 per cent. more, and gluten feed 160 per cent. more. This lessened energy value of the alfalfa has been shown to be due to its causing an increased metabolism in the animal organism.

7. In case of an average of three experiments (I, II and III) with cows, the dry matter in a ration composed of alfalfa, beet pulp and corn meal produced substantially as large a yield of milk and milk ingredients as did a like amount of dry matter in one composed of first-cut mixed hay, beet pulp and corn gluten products. The alfalfa seemed to act as a slight stimulus to production. In these experiments alfalfa and hay each furnished about 71 per cent. of the total dry food of the rations.

8. The animals showed a total gain in live weight of 13 pounds on the alfalfa ration, and 481 pounds on the hay ration, indicating that the less energy value of the alfalfa might have been responsible for this difference.

9. The protein contained in the alfalfa, beet pulp and corn meal ration, of which 78.2 per cent. was from alfalfa, seemed to be fully as effective in the formation of normal milk as did the protein contained in the hay, beet pulp and corn gluten ration.

10. The diuretic effect of the alfalfa appeared to be without influence in lessening the yield of milk and milk ingredients.

11. In case of the average of two experiments (IV and V), alfalfa proved slightly superior to rowen in the volume of milk produced. The difference, however (4.2 per cent. on the basis of equal amounts of dry matter in the two rations), was not sufficient to warrant any marked claim of superiority. This slight stimulating effect may be due to the superiority of the protein contained in the alfalfa.

12. The fat *percentage* in the milk produced on the alfalfa ration did not keep pace with the increased milk yield, for a like amount of dry matter in the alfalfa and rowen rations produced a like amount of milk fat.

13. The herd made a total gain in live weight of 16 pounds on the alfalfa ration, and lost a total of 24 pounds on the rowen ration, differences not sufficient to warrant any particular conclusion.

14. A good quality of rowen appears to be nearly as satisfactory a source of roughage for milk production as a like amount of a similar quality of alfalfa.

15. One experiment (VI) showed that a ration composed of one-half first-cut hay and one-half alfalfa, together with a little wheat bran and corn-and-cob meal, gave as satisfactory results as one consisting of first-cut hay, wheat bran, corn-and-cob meal and gluten feed. The former ration contained substantially home-grown products, and would render it unnecessary to purchase grain, the alfalfa furnishing the necessary extra protein required, and the corn-and-cob meal the necessary extra digestible matter.

16. One experiment (VII) indicated that reasonably good results can

be secured from a roughage ration composed of two-thirds alfalfa and one-third corn stover, together with a grain ration of corn-and-cob meal. If the stover is well cured and kept under cover it will give more satisfactory results than if left in the open during the winter. The yield of milk, however, on such a ration would not be quite equal to the yield on one composed of first-cut hay and a grain mixture of equal parts of wheat bran, corn-and-cob meal and gluten feed.

17. Too high an estimate should not be put upon the alfalfa, for while studies at this station and elsewhere have shown it to contain more protein than most other sources of roughage, and to equal wheat bran in feeding value, it is quite inferior as a source of energy or fat production to most of the concentrates.

18. In the light of our present knowledge it is preferable, particularly in the eastern states, not to use alfalfa as the entire source of roughage for milk production, but to feed one-half alfalfa and one-half hay, or two-thirds alfalfa and one-third corn stover, or 10 to 15 pounds of alfalfa and 1 bushel of silage daily. Such combinations, together with a grain ration of 70 to 80 per cent. corn-and-cob meal, and 20 to 30 per cent. wheat bran or oats or barley, ought to give quite satisfactory results.

INTRODUCTION.

In the year 1914 this station published Bulletin No. 154, entitled "Alfalfa," which related primarily to the growing of the crop in Massachusetts, based upon the results of home and co-operative experiments. It included specific directions for the general management of the crop.

The present bulletin summarizes the analyses and digestion trials made with alfalfa, both at this station and elsewhere, and presents the results of seven feeding experiments relative to its effect on milk production and its place in the dairy ration.

Alfalfa belongs to the same family of plants as the clover, pea and bean. The family name is *Leguminosæ*, and these plants are usually spoken of as legumes. It has been cultivated both in Asia and Europe for a long time, being known in Germany and France under the name of Luzerne. It has been grown with great success in California and in the hot semi-arid regions of the southwestern portions of our country. Of late years it has been cultivated with success in the northwestern States, and more recently it has been grown with considerable success in different portions of the Middle Atlantic and New England States. It is an especially deep-rooted perennial, and needs, among other things, a well-drained soil having a water table several feet below the surface, and an abundance of lime.

THE CHEMICAL COMPOSITION OF ALFALFA AND RED CLOVER.

The composition of these plants will vary more or less, depending upon the stage of growth at which they are cut, and whether the material is derived from the first, second or third cutting. The analysis of medium red clover is used for comparison. In order to make the analyses comparable, they have been brought (in case of the green samples) to substantially a like water basis. In case of the hays, a uniform moisture content of 14 per cent. has been employed.

TABLE I. — *Chemical Composition of Green Alfalfa and Red Clover.*

	Number of Analyses.	Water (Per Cent.).	Crude Ash (Per Cent.).	Crude Protein (Per Cent.).	Crude Fiber (Per Cent.).	Extract or Starchy Matter (Per Cent.).	Crude Fat (Per Cent.).
Alfalfa, average,[1]	143	74.7	2.4	4.5	7.0	10.4	1.0
Alfalfa, average,[2]	5	74.7	2.0	3.4	7.8	11.5	.5
Clover, average,[1]	85	73.8	2.1	4.1	7.3	11.7	1.0
Clover, average,[2]	13	73.8	2.4	4.1	7.5	11.5	.8
Alfalfa, before bloom,[1]	11	80.1	2.3	4.7	4.2	7.9	.8
Clover, before bloom,[2]	2	80.0	2.1	3.6	4.7	9.0	.6
Alfalfa, in bloom,[1]	27	74.1	2.5	4.4	7.8	10.4	.8
Clover, in bloom,[1]	36	72.5	2.0	4.1	8.2	12.1	1.1
Clover, in bloom,[2]	3	72.5	2.5	4.6	7.9	11.8	.8
Alfalfa, in seed,[1]	6	70.2	2.2	2.9	12.8	11.3	.6
Clover, in seed,[2]	2	70.2	2.7	4.5	8.6	13.1	.8

TABLE II. — *Chemical Composition of Alfalfa Hay (Red Clover Hay for Comparison).*

	Number of Analyses.	Water (Per Cent.).	Crude Ash (Per Cent.).	Crude Protein (Per Cent.).	Crude Fiber (Per Cent.).	Extract or Starchy Matter (Per Cent.).	Crude Fat (Per Cent.).
Alfalfa, average,[1]	250	14	8.1	14.0	26.6	35.1	2.2
Clover, average,[1]	76	14	7.0	12.6	25.2	38.1	3.1
Clover, average,[2]	15	14	7.8	13.5	24.6	37.6	2.5
Alfalfa, first cutting,[1]	46	14	8.3	13.1	29.0	34.0	1.6
Alfalfa, first cutting,[2]	3	14	6.7	14.5	27.5	35.8	1.5
Alfalfa, second cutting,[1]	33	14	8.3	13.6	29.6	32.9	1.6
Alfalfa, second cutting,[2]	1	14	5.8	13.2	32.7	33.2	1.1
Alfalfa, third cutting,[1]	17	14	9.0	13.8	26.8	34.7	1.7
Alfalfa, before bloom,[1]	11	14	9.2	20.2	18.8	33.9	3.9
Clover, before bloom,[1]	2	14	6.9	17.9	17.6	40.1	3.5
Clover, before bloom,[2]	1	14	9.6	15.3	24.4	35.0	1.7
Alfalfa, in bloom,[1]	31	14	9.3	13.9	28.1	33.0	1.7
Clover, in bloom,[2]	1	14	7.7	13.2	25.7	37.8	1.6
Alfalfa, in seed,[1]	10	14	6.7	11.7	26.5	38.7	2.4

A study of the analyses of both the alfalfa and clover shows that these plants resemble each other closely in general chemical composition. They contain considerably more protein than do the cereals and grasses, and less fiber and extract matter. If anything, the alfalfa is likely to be slightly richer in protein than the clover, and to contain a little more extract matter. Much, however, depends upon the exact stage of growth, the season and the soil on which the crops are grown.[1]

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[1] Feeds and Feeding, 15th edition, 1915, Henry & Morrison.

[2] Analyses made at the Massachusetts Agricultural Experiment Station.

THE DIGESTIBILITY OF ALFALFA HAY.

The general statement may be made that a food is valuable at least in so far as the animal can digest and assimilate it. A large number of digestion trials, principally with sheep, are on record, of which the following is a summary: —

TABLE III. — *Coefficients of Digestibility of Alfalfa Hay (Other Feeds for Comparison).*

	Number of Single Trials.	Dry Matter (Per Cent.).	Crude Ash (Per Cent.).	Crude Protein (Per Cent.).	Crude Fiber (Per Cent.).	Extract or Starchy Matter (Per Cent.).	Crude Fat (Per Cent.).
Alfalfa, average,[2]	109	60	50[2]	71	43	72	38
Clover, red, average,[2]	25	59	86[2]	59	54	66	57
Alfalfa, first cutting,[2]	53	59	54[2]	67	42	72	38
Alfalfa, second cutting,[2]	21	62	52[2]	76	44	74	40
Alfalfa, third cutting,[2]	6	58	44[2]	70	40	70	42
Alfalfa, bud to bloom,[2]	74	60	–	70	43	72	39
Clover, in bloom,[3]	4	62	58	62	53	68	54
Corn fodder, dent, mature for comparison,[3]	30	66	23	45	63	73	70
Timothy, average for comparison,[3]	58	55	39	48	50	62	50
Rowen (largely of grasses),[3]	12	65	–	70	66	65	47

In making a study of the above summary one notes, in case of the average results, that the digestibility of the dry matter of the alfalfa is about the same as of the clover. The crude protein of the alfalfa is noticeably more digestible than that of the clover (12 per cent. more), while the crude fiber shows a lower digestibility (11 per cent. less). The extract matter of the alfalfa is more digestible than that of the clover.

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[1] As alfalfa begins to blossom, its nitrogen content has been found to consist of 71.1 per cent. of true protein and 28.9 per cent. of so-called amids, although variations from these averages are pronounced (Mentzel u. Lengerke's Kalendar). Hart *et als.*, Research Bulletin No. 33, Wisconsin Experiment Station, found in a sample .31 per cent. of its nitrogen in the form of ammonia, 1.03 per cent. as an acid amid, and 10.17 per cent. as amino acids; the remainder, 88.49 per cent., existed as true protein. Headden, in Bulletin No. 124, Colorado Experiment Station, gives a considerable amount of data on the chemistry of alfalfa, recognizing sucrose, glucose and starch, 2.89 per cent. of galactan and from 11.44 to 13.38 per cent. of pentosans. Pott (Handbuch d. thier. Ernährung II Band p. 55) reports from 13.9 to 16.8 per cent. of pentosans. Lindsey and Holland found 4.71 per cent. of galactan in the alfalfa seed.

[2] Feeds and Feeding, 15th edition, 1915, Henry & Morrison.

[3] Lindsey's compilation, twenty-third report of the Massachusetts Agricultural Experiment Station, 1911.

The second cutting of alfalfa hay appears to be more digestible than the first and third cuttings, which are nearly equal in digestibility.

Comparing alfalfa in bloom with clover in bloom, one notes the same differences as in the average analyses of all samples: namely, that in case of the alfalfa the crude protein and extract matter are more digestible, and the crude fiber less digestible, than in the clover hay.

A comparison of our own results tells substantially the same story, as the following data show: —

TABLE IV. — *Coefficients of Digestibility of Alfalfa and Clover Hays (Our Results).*

	Number of Single Trials.	Dry Matter (Per Cent.).	Crude Ash (Per Cent.).	Crude Protein (Per Cent.).	Crude Fiber (Per Cent.).	Exrtact or Starchy Matter (Per Cent.).	Crude Fat (Per Cent.).
Alfalfa hay, ...	6	60	45	74	46	70	28
Clover hay, ...	4	62	58	61	53	68	54

In comparing the total digestibility of alfalfa hay with that of other feeds we have the following figures: alfalfa and clover, about 60 per cent.; timothy, 55 per cent.; rowen (largely of grasses), 65 per cent.; dent corn fodder, 66 per cent. It is evident, therefore, that in point of digestibility alfalfa and clover are rather more digestible than timothy hay, but less digestible than mature corn fodder or well-cured rowen.

Applying the average digestion coefficients to the average analyses of the several feeds, we have the following digestible nutrients for 1 ton: —

TABLE V. — *Digestible Nutrients in One Ton.*

	Crude Protein (Pounds).	Crude Fiber (Pounds).	Extract Matter (Pounds).	Crude Fat (Pounds).	Total Nutrients (Pounds).	Relative Digestion Values; Alfalfa = 100.	Relative Net Energy Values; Alfalfa = 100.
Alfalfa, ...	199	229	505	17	950	100	100
Red clover, . .	149	272	503	35	959	101	113
Timothy hay, . .	60	330	550	30	970	102	126
Rowen, ...	158	318	524	28	1,028	108	120[1]
Gluten feed,[2] . .	446	110	948	52	1,556	164	260

[1] Lindsey's calculations.

[2] For comparison.

One notes that of the several coarse fodders, alfalfa furnishes by far the most digestible protein. Thus, timothy hay yields only 60 pounds, clover and rowen 149 and 158 pounds, and alfalfa substantially 200 pounds in a ton. Alfalfa furnishes the largest amount of protein of any of the more common and useful coarse fodders. In case, however, of the total digestible nutrients, one notes but little difference between the timothy, clover and alfalfa. Rowen yields 8 per cent. more, while such a concentrate as gluten feed contains 64 per cent. more, than alfalfa. Total digestible matter, however, is not the most satisfactory unit of measure of the energy value of feedstuffs.

The unit known as net energy, obtained by deducting from the total energy in the feed the energy losses in feces, urine and heat radiated, is the best known method of comparison. On this basis Armsby's method of calculation, as indicated in the last column of the table, shows red clover to have 13 per cent. more net energy value than alfalfa, timothy hay 26 per cent., rowen 20 per cent., and gluten feed 160 per cent. While experiments conducted with the aid of the respiration calorimeter demonstrate these differences, it may be difficult to show such noticeable variations with the aid of ordinary feeding experiments.

FEEDING EXPERIMENTS WITH ALFALFA.

Experiments I, II and III.

Alfalfa, Beet Pulp and Corn Meal v. *Hay, Beet Pulp and Corn Gluten Products for Milk Production.*

The three experiments immediately following were made by the reversal method with two groups of six and one group of eight cows.

The objects of the several experiments were: —

1. To compare the effect of the dry matter and the protein in the two rations on the yield of milk and milk ingredients, and on the gain or loss in weight.

2. To see if the protein derived largely from alfalfa was as satisfactory for milk production as that secured largely from corn by-products.

3. To note if the diuretic effect of the alfalfa caused any noticeable milk shrinkage.[1]

4. To observe the possible adverse effect on milk production of the increased metabolism, caused by the alfalfa.

The rations were designated as the alfalfa and hay rations. The former consisted of alfalfa as the total roughage, plus beet pulp and corn meal; the latter, of hay as the roughage, plus beet pulp, gluten feed and gluten meal. The alfalfa ration naturally derived its protein largely from alfalfa, while in the hay ration a large part of the protein came from the gluten products. The digestible nutrients in each ration should be about the same.

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[1] Research Bulletin No. 33, Wisconsin Experiment Station.

TABLE VI. — *History of Cows.*

EXPERIMENT I.

Cows.	Breed.	Age (Years).	Last Calf dropped.	Served.	Milk Yield, Beginning of Trial (Pounds).
Samantha II, . .	Grade Holstein, .	7	Oct. 31, 1915	Dec. 27, 1915	40
Cecile II, . . .	Pure Jersey, . .	3	Nov. 11, 1915	Jan. 13, 1916	17
Betty III, . .	Grade Ayrshire, .	3	Sept. 14, 1915	- -	22
Fancy III, . .	Grade Jersey, .	8	Feb. 24, 1916	Apr. 3, 1916	29
Betty II, . . .	Grade Ayrshire, .	10	Aug. 31, 1915	Jan. 18, 1916	21
Ida II, . . .	Pure Jersey, . .	3	Jan. 29, 1916	Mar. 16, 1916	25

EXPERIMENT II.

Cows.	Breed.	Age (Years).	Last Calf dropped.	Served.	Milk Yield, Beginning of Trial (Pounds).
Colantha, . .	Grade Holstein, .	3	June 19, 1916	Sept. 15, 1916	23
Mary, . . .	Grade Holstein, .	6	Sept. 1, 1916	- -	31
Samantha II, . .	Grade Holstein, .	7	Aug. 14, 1916	Dec. 27, 1916	32
Samantha III, .	Grade Holstein, .	3	Aug. 6, 1916	Oct. 30, 1916	23
Red III, . . .	Grade Jersey, .	11	Aug. 18, 1916	Nov. 12, 1916	31
White, . . .	Grade Holstein, .	7	Aug. 27, 1916	Nov. 17, 1916	41

EXPERIMENT III.

Cows.	Breed.	Age (Years).	Last Calf dropped.	Served.	Milk Yield, Beginning of Trial (Pounds).
Cecile II, . . .	Grade Jersey, .	4	Oct. 14, 1916	Jan. 16, 1917	18
Betty II, . . .	Grade Ayrshire, .	11	Oct. 25, 1916	Apr. 16, 1917	29
Samantha II, . .	Grade Holstein, .	8	Aug. 14, 1916	Nov. 7, 1916	25
Colantha, . .	Grade Holstein, .	3	June 19, 1916	Oct. 20, 1916	20
Red IV, . . .	Grade Jersey, .	3	Sept. 26, 1916	Feb. 28, 1917	21
Ida II, . . .	Pure Jersey, . .	4	Dec. 27, 1916	Feb. 15, 1917	26
White, . . .	Grade Holstein, .	7	Aug. 27, 1916	- -	27
Samantha III, .	Grade Holstein, .	3	Aug. 6, 1916	Oct. 27, 1916	19

TABLE VII. — *Duration of Experiments.*

DATES.	Hay-ration Cows.	Alfalfa-ration Cows.	Length of Period (Weeks).
	EXPERIMENT I.		
Apr. 10 through May 14, 1916,	Samantha II, Cecile II, Betty III.	Fancy III, Betty II, Ida II.	5
May 26 through June 29, 1916,	Fanny III, Betty II, Ida II.	Samantha II, Cecile II, Betty III.	5
	EXPERIMENT II.		
Oct. 20 through Nov. 23, 1916,	Colantha, Mary, Samantha II.	Samantha III, Red III, White.	5
Dec. 4, 1916, through Jan. 7, 1917.	Samantha III, Red III, White.	Colantha, Mary, Samantha II.	5
	EXPERIMENT III.		
Jan. 29 through Mar. 4, 1917,	Cecile II, Betty II, Samantha II, Colantha.	Red IV, Ida II, White, Samantha III.	5
Mar. 15 through Apr. 18, 1917,	Red IV, Ida II, White, Samantha III.	Cecile II, Betty II, Samantha II, Colantha.	5

Care of Animals. — The animals were well cared for in all cases, and turned into a barnyard from four to nine hours daily, depending upon the weather conditions. They were fed twice daily; the hay was given some time before milking, and the grain just before milking in the afternoon, while in the morning the grain was given just before and the hay just after milking. Water was supplied constantly by the aid of a self-watering device. During the winter the barn wings were kept at a temperature of about 50° F. with the aid of steam heat.

Character of Feeds. — The hay was of mixed grasses with some clover, cut upon the station farm. An effort was made to have it of as uniform quality as possible in each experiment. The alfalfa in the first experiment was said to be second cutting, grown in Michigan. It was bright, leafy and sweet, but rather coarse. In the second experiment about one-third of the alfalfa was from the same source, and two-thirds were second and third cutting grown upon the station farm. In the third experiment it was third cutting grown upon the college farm.

The beet pulp in the first and second experiments was molasses beet pulp, and in the third experiment, plain dried pulp, — all of good quality.

The gluten feed and Diamond gluten meal were of the usual satisfactory quality. The same may be said of the corn meal, except that it was rather moist, and it was necessary to purchase it in small amounts to prevent heating.

Sampling Feeds and Milk. — The hays were sampled at the beginning, middle and end of each half of the trial by taking forkfuls of the daily weighings, running same through a power cutter, sub-sampling and placing the laboratory samples in large glass-stoppered bottles; these bottles properly labeled were brought to the laboratory immediately. The grains were sampled daily by placing definite amounts in glass-stoppered bottles, properly labeled, and brought to the laboratory at the end of each half of the trial. Dry matter determinations were made and samples prepared for complete analysis. The milk was sampled for five consecutive days in each week, preserved with formalin, and the composite analyzed for total solids and for fat by the Babcock method, and for nitrogen. The method of sampling consisted in mixing the milk as soon as drawn with the aid of a perforated tin disk attached to the end of a stout tin handle, by moving the same up and down gently for a number of times, and then taking out a definite amount with a small long-handled tin dipper.

TABLE VIII. — *Analyses of Feeds (Per Cent.).*

Experiment.	FEED.	Water.	DRY MATTER.					
			Ash.	Crude Protein.	True Protein.	Fiber.	Extract Matter.	Fat.
I	Hay,	11.62–13.15	8.02	9.13	7.37	35.07	45.27	2.51
II	Hay,	11.22–11.67	6.34	8.10	7.20	35.19	48.12	2.25
III	Hay,	10.25–11.04	6.46	8.42	7.35	34.06	48.66	2.40
I	Alfalfa,	12.86–15.16	7.24	14.93	11.40	41.22	35.14	1.47
II	Alfalfa (old),	12.65–14.18	7.22	15.31	11.12	40.56	35.52	1.39
	Alfalfa (new),	12.43–12.81	7.92	17.41	14.04	31.42	41.42	1.83
III	Alfalfa,	11.21–11.79	7.16	14.89	11.83	35.75	40.05	2.15
I	Beet pulp,	11.40–11.98	4.41	10.40	7.65	17.72	66.86	.61
II	Beet pulp,	12.23–12.76	4.09	10.31	–	18.24	66.73	.63
III	Beet pulp,	10.21–13.53	2.79	11.02	–	21.22	64.28	.69
I	Gluten feed,	8.41–10.85	5.11	30.08	21.39	7.13	54.95	2.73
II	Gluten feed,	10.25–11.63	4.82	30.99	–	7.13	54.64	2.42
III	Gluten feed,	9.47– 9.72	5.00	31.54	–	8.03	53.36	2.07
I	Gluten meal,	8.61– 8.96	.87	48.78	46.23	1.46	47.95	.94
II	Gluten meal,	9.26– 9.88	1.20	49.38	–	1.63	46.88	.91
III	Gluten meal,	8.32– 8.57	1.04	50.50	–	1.76	45.74	.96
I	Corn meal,	14.53–16.40	1.70	10.34	9.52	1.72	82.61	3.63
II	Corn meal,	13.27–13.64	1.51	10.37	–	2.62	81.42	4.08
III	Corn meal,	11.53–11.65	1.32	10.49	–	2.51	81.75	3.93

The analytical data are expressed in dry matter because of variations in moisture. From an analytical standpoint the hays resemble each other closely; the same may be said of the alfalfa, except that the sample in the third experiment contained somewhat less fiber. The albuminoid matter was determined by the Stutzer method, which includes both the amino acids and the acid amids. In view of the fact that the amino acids are supposed to be valuable in protein synthesis, the Stutzer method of separation is not held to be of as much importance as formerly. The hay contained 14.5 per cent. and the alfalfa 22.64 per cent. of its nitrogen in the non-albuminoid form.

The beet pulp used in the third experiment showed rather more fiber and a little less extract matter, because of the lack of the molasses.

The several lots of the different grains were quite uniform in character. The one sample of gluten feed on which a non-albuminoid nitrogen test was made showed some 29 per cent. of this ingredient, indicating the addition of considerable "steep water" in its manufacture.

TABLE IX. — *Average Daily Ration consumed per Cow* (*Pounds*).

EXPERIMENT I.

Number of Cows.	CHARACTER OF RATION.	Alfalfa.	Hay.	Beet Pulp.	Gluten Feed.	Gluten Meal.	Corn Meal.
6	Alfalfa, . .	16.47–24.50 18.96	–	4.00–5.00 4.17	–	–	3.31–7.75 4.55
6	Hay, . .	–	16.00–24.00 18.77	4.00–5.00 4.17	.00–6.00 1.83	1.00–3 00 2.33	–

EXPERIMENT II.

Number of Cows.	CHARACTER OF RATION.	Alfalfa.	Hay.	Beet Pulp.	Gluten Feed.	Gluten Meal.	Corn Meal.
6	Alfalfa, . .	19.14–22.83 20.65	–	3.00–5.00 3.67	–	–	4.00–6.00 5.13
6	Hay, . .	–	17.77–22.00 19.96	3.00–5.00 3.67	.75–3.88 1.73	0.00–4.00 3.17	–

EXPERIMENT III.

Number of Cows.	CHARACTER OF RATION.	Alfalfa.	Hay.	Beet Pulp.	Gluten Feed.	Gluten Meal.	Corn Meal.
8	Alfalfa, . .	16.00–22.00 20.63	–	3.00–4.00 3.13	–	–	3.09–5.16 4.32
8	Hay, . .	–	15.69–22.00 20.36	3.00–4.00 3.13	.00–2.00 .75	2.67–4.50 3.39	–

The reason for presenting the above concise tables is to give the interested student an idea of the amounts fed daily in the two different rations, and to emphasize their uniformity. In the first experiment more corn meal was fed than gluten products, because of its larger moisture content.

TABLE X. — *Estimated Dry and Digestible Nutrients in Average Daily Rations (Pounds).*

EXPERIMENT I.

CHARACTER OF RATION.	Dry Matter.	DIGESTIBLE NUTRIENTS.					
		Protein.	Fiber.	Extract Matter.	Fat.	Total.	Nutritive Ratio.
Alfalfa, . . .	23.82	2.23	3.37	9.28	.22	15.10	1:5.9
Hay, . . .	23.93	2.44	4.09	8.48	.27	15.28	1:5.4

EXPERIMENT II.

CHARACTER OF RATION.	Dry Matter.	Protein.	Fiber.	Extract Matter.	Fat.	Total.	Nutritive Ratio.
Alfalfa, . . .	25.64	2.66	3.28	10.08	.25	16.27	1:5.2
Hay, . . .	25.31	2.67	4.29	9.09	.25	16.30	1:5.2

EXPERIMENT III.

CHARACTER OF RATION.	Dry Matter.	Protein.	Fiber.	Extract Matter.	Fat.	Total.	Nutritive Ratio.
Alfalfa, . . .	24.84	2.39	3.28	9.76	.28	15.71	1:5.7
Hay, . . .	24.72	2.61	4.23	8.65	.25	15.74	1:5.1

The above data were secured by applying average digestion coefficients to the analyses of the several feeds, and multiplying by the amounts of dry matter consumed daily. It is at best but an estimate. It serves, however, to give the reader an idea of the uniformity of the two rations, in so far as digestible nutrients and nutritive ratio are concerned.

1. The effect of the total dry matter contained in the two separate rations, and also the effect of the dry matter in the hay and in the alfalfa upon the yield of milk and milk ingredients.

TABLE XI. — *Total Dry Matter consumed in Each Feed and in the Complete Ration (Pounds).*

Number of Cows.	ALFALFA.		HAY.		BEET PULP.[1]		GLUTEN FEED.		GLUTEN MEAL.		CORN MEAL.		TOTAL.	
	Total.	Daily Average.	Total.	Daily Average.	Total.	Daily Average.	Total.	Daily Average.	Total.	Daily Average.	Total.	Daily Average.	Alfalfa Ration.	Hay Ration.
EXPERIMENT I.														
6	3,421	16.29	3,455	16.45	773	3.68	349	1.67	447	2.13	809	3.85	5,003	5,024
EXPERIMENT II.														
6	3,775	17.99	3,711	17.69	675	3.21	325	1.54	602	.87	930	4.44	5,380	5,313
EXPERIMENT III.														
8	5,116	18.26	5,093	18.20	777	2.76	190	.68	866	3.09	1,071	3.82	6,964	6,926
TOTALS.														
	12,312	–	12,259	–	2,225	–	864	–	1,915	–	2,810	–	17,347	17,263

[1] Beet pulp was fed in each half of each trial in substantially like amounts.

A study of Table XI indicates that the total dry matter consumed in each ration was substantially the same, the most noticeable variation being in Experiment II. The total dry matter consumed in the three experiments was nearly the same, differing by only about one-half per cent.

The dry matter consumed in the form of alfalfa and in hay in the three experiments (12,312 pounds and 12,259 pounds) likewise shows a variation of substantially only one-half per cent.

TABLE XII. — *Total Milk and Milk Ingredients produced.*

Number of Cows.	CHARACTER OF RATION.	Milk produced (Pounds).	Solids (Per Cent.).	Solids (Pounds).	Fat (Per Cent.).	Fat (Pounds).	Nitrogen (Per Cent.).	Nitrogen (Pounds).
	EXPERIMENT I.							
6	Alfalfa, . . .	4,916	12.78	628.1	4.21	206.6	.51	25.10
6	Hay, . . .	4,870	13.47	655.9	4.73	230.5	.54	26.38
	EXPERIMENT II.							
6	Alfalfa, . . .	4,856	13.21	641.5	4.57	222.1	.54	26.42
6	Hay, . . .	4,776	13.20	630.5	4.53	216.3	.54	25.61
	EXPERIMENT III.							
8	Alfalfa, . . .	6,094	14.04	855.6	5.02	306.2	.59	35.73
8	Hay, . . .	6,087	14.18	862.9	5.10	310.4	.60	36.46
	TOTALS.							
	Alfalfa, . . .	15,866	13.34	2,125.2	4.60	734.9	.55	87.25
	Hay, . . .	15,733	13.62	2,149.3	4.79	757.2	.56	88.45

Table XII shows that in Experiment I the milk yield favored the alfalfa ration by about 1 per cent., while in the second experiment the difference was about 2 per cent. In the third experiment the difference was very slight, — only 7 pounds. The total of the three experiments gives a yield of 15,866 pounds for the alfalfa ration, and 15,733 pounds for the hay ration, a difference of about nine-tenths of 1 per cent. in favor of the alfalfa.

In Experiment I, for some reason, the yields of total solids and total fat were noticeably greater (4.4 and 11.1 per cent.) on the hay ration. These results, however, were not made emphatic by the two other experiments; hence one is in no way justified in assuming that the alfalfa influenced the milk composition. A definite amount of dry matter, therefore, in each of the rations produced substantially the same results in the yield of milk and milk ingredients. One sees that the alfalfa stimulated slightly the yield of milk without correspondingly increasing the solids.

TABLE XIII. — *Gain or Loss in Live Weight (Pounds).*

EXPERIMENT.	GAIN.		LOSS.		NET.	
	Alfalfa Ration.	Hay Ration.	Alfalfa Ration.	Hay Ration.	Alfalfa Ration.	Hay Ration.
I,	105	292	-	-	+105	+292
II,	63	60	73	7	—10	+53
III,	26	136	108	-	—82	+136
Totals,	-	-	-	-	+13	+481

In Experiment I, when several of the animals were somewhat advanced in the milking period, each herd showed an increase in live weight. In Experiment II the cows were comparatively fresh and not as much gain was noted; in this experiment the alfalfa ration produced a slight decrease in the weight of the herd. In Experiment III, conducted during the winter and early spring, a decrease was also noted when the alfalfa ration was fed. It may be remarked that in each experiment it was our object to feed slightly less nutrients than calculations showed to be necessary to maintain weight and to meet the demands for milk, so that the full effect of each ration would be felt. It seems evident that while the alfalfa and corn meal ration fully maintained the milk yield, it was not as effective in increasing the live weight as was the hay and gluten ration.

2. The effect of different forms of protein on the yield and character of the milk.

TABLE XIV. — *Protein consumed in the Feeds and Rations (Pounds).*

EXPERIMENT.	Alfalfa.	Hay.	Beet Pulp.[1]	Gluten Products.	Corn Meal.	TOTALS.	
						Alfalfa Ration.	Hay Ration.
I,	510.8	315.4	80.4	323.0	83.7	674.9	718.8
II,	631.2	306.0	69.6	398.0	96.4	797.2	773.6
III,	761.8	428.8	85.6	497.2	112.3	959.7	1,011.6
Totals,	1,903.8	1,050.2	235.6	1,218.2	292.4	2,431.8	2,504.0

[1] Beet pulp was fed in each half of each experiment in substantially like amounts.

TABLE XV. — *Protein Found in the Milk (Pounds).*

EXPERIMENT.	Alfalfa Ration.	Hay Ration.
I,	156.9	164.9
II,	165.1	166.0
III,	223.3	227.9
Totals,	545.3	558.8

In case of the alfalfa ration, the total amount of protein consumed in the three experiments was 2,431.8 pounds, of which 1,903.8 pounds, or 78.2 per cent., came from the alfalfa, and 528 pounds, or 21.7 per cent., came from the beet pulp and corn meal. In the hay ration, of the total of 2,504 pounds consumed, 1,050.2 pounds, or 41.9 per cent., came from the hay, and 1,453.6 pounds, or 58.1 per cent., came from the beet pulp and corn gluten products.

The total protein in the milk (N × 6.25) produced by the alfalfa ration was 545.3 pounds, and by the hay ration 558.8 pounds, showing that the alfalfa ration, in which 78.2 per cent. of the protein was derived from alfalfa, produced as much milk protein and substantially as much milk solids as did the hay ration; or, in other words, that the protein of the alfalfa was fully as satisfactory a source of protein for milk formation as was that in the hay and corn gluten. An objection might be raised to this conclusion because 528 pounds of protein (21.7 per cent. of the total amount fed) was derived from beet pulp and corn meal, and this amount of protein was nearly equal to the amount produced in the milk. It must be remembered, however, that of the 528 pounds, scarcely two-thirds would be digestible and hence available for milk production. Although it is quite possible that the protein from the beet pulp and corn meal was also utilized for the formation of the nitrogenous matter in the milk, it is fairly safe to conclude that the alfalfa protein proved fully as satisfactory a source for milk formation as did that contained in the hay and corn gluten products. Hart and Humphrey[1] have more completely demonstrated this by feeding to two cows a ration composed of alfalfa and starch, and they found that the protein in the alfalfa was equal to that contained in a ration composed entirely of corn products.

3. The diuretic effect of the alfalfa.

The same authors have shown in two experiments with two cows that the substitution of alfalfa in place of corn products caused a marked increase in the excretion of urine and a shrinkage in the milk yield, in some cases amounting to substantially 25 per cent.

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[1] Loc. cit.

Because of the number of cows involved, it was not practicable to determine the urine output nor the water drunk. On the basis, however, of the volume of milk as well as the total solids yielded, as stated in Table XII, it did not appear in the five weeks' period that the alfalfa exerted any adverse effect. A study of the daily records of individual cows, especially during the transition period from the hay to the alfalfa ration, confirms this conclusion. In fact, the alfalfa seemed to act as a slight stimulus to production. Whether this was due to the favorable character of the proteins or to other causes is not clear.

4. The influence of the increased metabolism caused by the alfalfa on the yield of milk and on live weight.

Armsby[1] has shown that by increasing the metabolism alfalfa is decidedly inferior as a source of energy to timothy hay, in the proportion of 34.1 to 48.63 therms of net energy per 100 pounds of dry mattter; *i.e.*, a decrease of some 30 per cent.[2] Inasmuch as the dry matter in alfalfa and in hay comprised some 71 per cent. of the total dry matter contained in each of the two rations, it would seem as though the influence of the increased metabolism caused by the alfalfa would be noticeable, even though the hay was not what might be classed as timothy. The yields of milk and milk solids fail to show any unfavorable effect of this factor. Only in the case of the live weight (Table XIII) produced does one notice a possible adverse effect of the alfalfa, which might be attributed to its inferior energy value.

Additional Experimental Data.

TABLE XVI. — *Total Rations Consumed by Each Cow (Pounds).*

EXPERIMENT I.

Cows.	Alfalfa.	Hay.	Beet Pulp.[3]	Corn Meal.	Gluten Feed.	Gluten Meal.
Fancy III,	735.0	714.5	140	151.0	35.00	105.0
Betty II,	609.5	604.5	140	151.0	52.50	87.5
Ida II,	611.0	602.5	140	151.0	52.50	87.5
Samantha II,	857.5	840.0	175	271.0	210.00	35.0
Cecile II,	576.5	560.0	140	116.0	35.00	70.0
Betty III,	589.5	620.5	140	116.0	–	105.0

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[1] The Nutrition of Farm Animals, pp. 660, 663.

[2] Most other hays (mixtures of grasses) are also shown to be quite superior to alfalfa as a source of energy.

[3] The same amount fed in each half.

TABLE XVI. — *Total Rations Consumed by Each Cow* — Concluded.

EXPERIMENT II.

Cows.	Alfalfa.	Hay.	Beet Pulp.	Corn Meal.	Gluten Feed.	Gluten Meal.
Samantha III,	735.0	700.0	105	175.0	26.25	140.0
Red III,	700.0	665.0	140	140.0	135.64	-
White,	799.0	770.0	140	210.0	96.25	105.0
Colantha,	697.0	700.0	105	183.8	35.00	140.0
Mary,	670.0	622.0	105	183.8	35.00	140.0
Samantha II,	735.0	735.0	175	183.8	35.00	140.0

EXPERIMENT III.

Cows.	Alfalfa.	Hay.	Beet Pulp.	Corn Meal.	Gluten Feed.	Gluten Meal.
Red IV,	700.0	688.0	105	144.5	35.00	93.5
Ida II,	700.0	700.0	105	144.5	35.00	105.0
White,	770.0	770.0	105	162.1	-	157.5
Samantha III,	770.0	770.0	105	144.5	-	137.0
Cecile II,	560.0	549.0	140	108.2	-	105.0
Betty II,	770.0	727.0	105	180.6	70.00	105.0
Samantha II,	735.0	731.0	105	180.6	70.00	105.0
Colantha,	770.0	765.0	105	144.5	-	140.0

TABLE XVII. — *Changes in Live Weight (Pounds).*

EXPERIMENT I.

Cows.	Alfalfa.	Hay.
Fancy III,	+29	+20
Betty II,	+10	+93
Ida II,	+8	+28
Samantha II,	+13	+52
Cecile II,	+23	+51
Betty III,	+22	+48
Totals,	+105	+292

TABLE XVII. — *Changes in Live Weight (Pounds)* — Concluded.

EXPERIMENT II.

Cows.	Alfalfa.	Hay.
Samantha III,	+17	+5
Red III,	+38	—5
White,	+8	+45
Colantha,	—32	+7
Mary,	±	+3
Samantha II,	—41	—2
Totals,	—10	+57

EXPERIMENT III.

Red IV,	—4	+7
Ida II,	—7	+19
White,	—35	+1
Samantha III,	+9	+27
Cecile II,	—16	+1
Betty II,	—24	+10
Samantha II,	+17	+16
Colantha,	—22	+55
Totals,	—102	+136

TABLE XVIII. — *Yield of Milk and Milk Ingredients.*

EXPERIMENT I.

Alfalfa Ration.

Cows.	Milk (Pounds).	Solids (Per Cent.).	Solids (Pounds).	Fat (Per Cent.).	Fat (Pounds).	Nitrogen (Per Cent.).	Nitrogen (Pounds).
Fancy III,	1,044.4	11.97	125.01	3.82	39.89	.46	4.80
Betty II,	687.2	12.96	89.06	4.32	29.69	.53	3.64
Ida II,	791.0	13.45	106.39	4.68	37.02	.51	4.03
Samantha II,	1,186.0	12.33	146.23	3.85	45.66	.50	5.93
Cecile II,	549.7	14.42	79.27	5.06	27.81	.61	3.35
Betty III,	656.2	12.52	82.16	4.04	26.51	.51	3.35
Totals,	4,914.5	-	628.12	-	206.58	-	25.10

TABLE XVIII. — *Yield of Milk and Milk Ingredients* — Continued.

EXPERIMENT I. — *Concluded.*

Hay Ration.

Cows.	Milk (Pounds).	Solids (Per Cent.).	Solids (Pounds).	Fat (Per Cent.).	Fat (Pounds).	Nitrogen (Per Cent.).	Nitrogen (Pounds).
Fancy III,	992.7	12.77	126.77	4.36	43.28	.50	4.96
Betty II,	631.3	13.82	87.25	4.95	31.25	.56	3.54
Ida II,	670.5	14.38	96.42	5.26	35.27	.58	3.89
Samantha II,	1,280.3	12.79	163.75	4.36	55.82	.51	6.53
Cecile II,	581.0	14.95	86.86	5.56	32.30	.62	3.60
Betty III,	714.2	13.28	94.85	4.56	32.57	.54	3.86
Totals,	4,870.0	–	655.90	–	230.49	–	26.38

EXPERIMENT II.

Alfalfa Ration.

Samantha III,	630.1	14.00	88.21	4.75	29.92	.59	3.72
Red III,	847.2	13.12	111.15	4.82	40.84	.52	4.41
White,	953.1	12.54	119.52	4.48	42.70	.52	4.96
Colantha,	689.8	13.10	90.36	4.19	28.90	.55	3.79
Mary,	874.8	12.71	111.19	4.10	35.86	.50	4.37
Samantha II,	861.0	14.06	121.06	5.10	43.91	.60	5.17
Totals,	4,856.0	–	641.49	–	222.14	–	26.42

Hay Ration.

Samantha III,	621.7	14.09	87.60	4.72	29.34	.60	3.73
Red III,	631.5	13.51	85.32	5.00	31.58	.55	3.47
White,	954.7	12.75	121.72	4.45	42.48	.53	5.06
Colantha,	709.1	13.03	92.40	4.25	30.14	.54	3.83
Mary,	955.2	12.58	120.16	4.21	40.21	.46	4.39
Samantha II,	903.9	13.64	123.29	4.71	42.57	.59	5.33
Totals,	4,776.1	–	630.49	–	216.32	–	25.61

TABLE XVIII. — *Yield of Milk and Milk Ingredients* — Concluded.

EXPERIMENT III.

Alfalfa Ration.

Cows.	Milk (Pounds).	Solids (Per Cent.).	Solids (Pounds).	Fat (Per Cent.).	Fat (Pounds).	Nitrogen (Per Cent.).	Nitrogen (Pounds).
Red IV,	775.0	14.54	112.69	5.44	42.16	.60	4.65
Ida II,	877.0	14.41	129.38	5.40	47.36	.57	5.00
White,	865.4	13.13	113.63	4.73	40.93	.54	4.67
Samantha III,	648.1	13.94	90.35	4.72	30.59	.61	3.95
Cecile II,	597.6	15.50	92.63	6.03	36.04	.64	3.82
Betty II,	950.3	13.87	131.81	4.89	46.47	.57	5.42
Samantha II,	711.2	13.76	97.86	4.65	33.07	.61	4.34
Colantha,	669.3	13.48	90.22	4.42	29.58	.58	3.88
Totals,	6,093.9	–	855.57	–	306.20	–	35.73
Hay Ration.							
Red IV,	738.2	14.72	108.66	5.43	40.08	.62	4.58
Ida II,	756.2	15.05	113.81	5.75	43.48	.61	4.61
White,	883.9	13.45	118.88	4.83	42.69	.58	5.13
Samantha III,	662.8	14.31	94.85	4.88	32.35	.61	4.04
Cecile II,	583.1	15.15	88.34	5.72	33.35	.63	3.67
Betty II,	899.2	14.25	128.13	5.22	46.94	.59	5.31
Samantha II,	893.8	13.55	121.11	4.74	42.40	.59	5.30
Colantha,	670.0	13.30	89.11	4.34	29.08	.57	3.82
Totals,	6,087.2	–	862.89	–	310.37	–	36.46

EXPERIMENTS IV AND V.

Alfalfa v. *Rowen for Milk Production.*

The claims made for alfalfa as a coarse fodder *par excellence* for milk production led us to compare the same with the second cutting of grass known as rowen.

Two experiments were conducted with four cows each by the reversal method. The methods followed in the experiments, such as care of cows, sampling of feeds and milk, are the same as those described in previous experiments of a similar nature.

TABLE XIX. — *History of Cows.*

EXPERIMENT IV.

Cows.	Breed.	Age (Years).	Last Calf dropped.	Served.	Weight (Pounds).	Milk Yield, Beginning of Trial (Pounds).	Fat (Per Cent.).
Fancy III,	Grade Jersey,	8	Jan. 10, 1917	– –	900	38	4.73
Peggy,	Grade Jersey,	4	Sept. 19, 1916	Oct. 27, 1916	750	21	6.43
Red III,	Grade Jersey,	11	Aug. 18, 1916	– –	935	21	5.25
Mary,	Grade Holstein,	6	Sept. 1, 1916	– –	955	25	3.90

EXPERIMENT V.

Cows.	Breed.	Age (Years).	Last Calf dropped.	Served.	Weight (Pounds).	Milk Yield, Beginning of Trial (Pounds).	Fat (Per Cent.).
Cecile II,	Pure Jersey,	4	Oct. 4, 1916	Jan. 16, 1917	670	17	6.10
Betty II,	Grade Ayrshire,	11	Oct. 25, 1916	Apr. 16, 1917	900	28	4.90
Red IV,	Grade Jersey,	3	Sept. 20, 1916	Jan. 16, 1917	800	21	5.50
Ida II,	Grade Jersey,	4	Dec. 27, 1916	Jan. 26, 1917	850	21	5.90

TABLE XX. — *Duration of Experiments.*

EXPERIMENT IV.

DATES.	Rowen-ration Cows.	Alfalfa-ration Cows.	Length of Period (Weeks).
Feb. 26 through April 1, 1917, .	Mary, Red III, . .	Fancy III, Peggy, .	5
April 12 through May 16, 1917, .	Fancy III, Peggy, .	Mary, Red III, . .	5

EXPERIMENT V.

DATES.	Rowen-ration Cows.	Alfalfa-ration Cows.	Length of Period (Weeks).
April 26 through May 23, 1917, .	Red IV, Ida II, . .	Cecile II, Betty II, .	4
June 3 through June 30, 1917, .	Cecile II, Betty II, .	Red IV, Ida II, . .	4

Character of Feeds. — The rowen represented the second cutting of grass. It was well cured and in good condition, but it did not show a digestibility equal to the average, as the results stated below will show. The alfalfa was of good quality; it was grown in New York State, and while rather coarse was said to be third cutting. The corn meal and bran were of the usual good quality.

TABLE XXI. — *Coefficients of Digestibility secured for Rowen and Alfalfa.*

	Trials.	Dry Matter.	Ash.	Protein.	Fiber.	Extract Matter.	Fat.
Rowen, ...	2	61	34	60	68	63	32
Average (previous trials), .	12	65	–	70	66	65	47
Alfalfa, ...	4	58	43	72	46	66	24
Average (previous trials, third cutting).	6	58	44	70	40	70	42

It will be noted that the digestibility of the protein in the rowen was noticeably below the average. The alfalfa coefficients agreed well with the average results of other trials.

The protein in the rowen showed a digestibility inferior to that of the protein in the alfalfa, while the fiber in the alfalfa was noticeably less digestible than the fiber in the rowen. The low digestibility of the fiber in the alfalfa is characteristic of the plant.

TABLE XXII. — *Analyses of Feeds (Per Cent.).*

Experiment.	FEED.	Water.	DRY MATTER.					
			Ash.	Crude Protein.	True Protein.	Fiber.	Extract Matter.	Fat.
IV	Rowen,	10.29–11.13	8.87	12.59	10.05	28.57	45.93	4.04
V	Rowen,	9.08–10.96	7.66	11.99	10.48	26.33	50.36	3.66
	Average,	–	8.27	12.29	10.27	27.45	48.15	3.85
IV	Alfalfa,	11.84–12.17	7.21	15 58	12.59	33.13	41.89	2.19
V	Alfalfa,	11.58–11.87	7.05	16.29	13.16	29.65	44.68	2.33
	Average,	–	7.13	15.94	12.88	31.39	43.29	2.26
IV	Grain mixture,[1]	12.23–12.65	3.32	12.60	–	5.10	74.50	4.48
V	Grain mixture,[1]	13.07–13.18	3.43	13.02	–	5.24	74.80	3.51

[1] The grain mixture consisted of 30 per cent. bran and 70 per cent. corn meal.

Applying the digestion coefficients secured by our experiments to the analyses of rowen and alfalfa, the following amounts of organic nutrients are found to be digestible in 2,000 pounds of dry matter.

TABLE XXIII. — *Digestible Organic Nutrients in 2,000 Pounds Dry Matter (Pounds).*

FEED.	Protein.	Fiber.	Extract Matter.	Fat.	Totals.
Rowen,	147.48	373.32	606.69	24.64	1,152.13
Alfalfa,	229.54	288.72	571.43	10.85	1,100.61

The alfalfa furnished 82.06 pounds more of digestible crude protein than did the rowen, but less digestible fiber and extract matter, and rather less total digestible organic nutrients. While the rowen contains noticeably less digestible protein, the above computation indicates that it should prove approximately as valuable for milk production as alfalfa.

TABLE XXIV. — *Total Rations consumed by Each Cow (Pounds).*

EXPERIMENT IV.

Cows.	Rowen.	Alfalfa.	Grain Mixture.	
			Rowen Ration.	Alfalfa Ration.
Mary,	626	610	210	210
Red III,	663	665	195	210
Fancy III,	768	770	350	350
Peggy,	630	630	210	210
Totals,	2,687	2,675	965	980

EXPERIMENT V.

Cows.	Rowen.	Alfalfa.	Grain Mixture.	
			Rowen Ration.	Alfalfa Ration.
Red IV,	504	504	168	168
Ida II,	504	504	168	168
Cecile II,	476	476	196	196
Betty II,	588	578	224	224
Totals,	2,072	2,062	756	756
Totals (both experiments),	4,759	4,737	1,721	1,736

The totals show that in the two experiments substantially like amounts of rowen or alfalfa and grain were fed.

TABLE XXV. — *Total Dry Matter consumed in Each Feed (Pounds).*

Experiment.	Rowen.	Alfalfa.	Grain Mixture.	
			Rowen Ration.	Alfalfa Ration.
IV,	2,401	2,354	845	857
V,	1,864	1,828	657	657
Totals,	4,265	4,182	1,502	1,514

About 2 per cent. more dry matter in the form of rowen was fed than in alfalfa, while the dry matter in the form of grain was about the same. If the rowen was equal to the alfalfa, one would expect fully as good results in milk yield and live weight.

TABLE XXVI. — *Gain or Loss in Live Weight (Pounds).*

EXPERIMENT.	GAIN.		LOSS.		NET.	
	Rowen Ration.	Alfalfa Ration.	Rowen Ration.	Alfalfa Ration.	Rowen Ration.	Alfalfa Ration.
IV,	26	10	18	30	+8	—20
V,	5	59	37	0	—32	+36
Totals,	-	-	-	-	—24	+16

There appeared to be a slight gain on the alfalfa and a slight loss on the rowen ration.

TABLE XXVII. — *Yield of Milk and Milk Ingredients.*

EXPERIMENT IV.

Rowen Ration.

Cows.	Milk (Pounds).	Solids (Per Cent.).	Solids (Pounds).	Fat (Per Cent.).	Fat (Pounds).	Nitrogen (Per Cent.).	Nitrogen (Pounds).
Mary,	770.2	12.62	97.20	4.17	32.12	.52	4.01
Red III,	596.1	14.26	85.00	5.52	32.90	.61	3.64
Fancy III,	1,132.9	13.34	151.13	4.89	55.40	.49	5.55
Peggy,	609.0	15.51	94.46	6.23	38.25	.62	3.78
Totals,	3,108.2	13.76[1]	427.79	5.10[1]	158.67	.55[1]	16.98

Alfalfa Ration.

Cows.	Milk (Pounds).	Solids (Per Cent.).	Solids (Pounds).	Fat (Per Cent.).	Fat (Pounds).	Nitrogen (Per Cent.).	Nitrogen (Pounds).
Mary,	737.4	12.51	92.25	3.94	29.05	.51	3.76
Red III,	608.3	13.42	81.63	5.01	30.48	.59	3.59
Fancy III,	1,272.1	13.03	165.75	4.47	56.86	.53	6.74
Peggy,	650.7	15.43	100.40	6.36	41.38	.63	4.10
Totals,	3,268.5	13.46[1]	440.03	4.82[1]	157.77	.56[1]	18.19

EXPERIMENT V.

Rowen Ration.

Cows.	Milk (Pounds).	Solids (Per Cent.).	Solids (Pounds).	Fat (Per Cent.).	Fat (Pounds).	Nitrogen (Per Cent.).	Nitrogen (Pounds).
Red IV,	538.4	15.13	81.46	5.91	31.82	.59	3.18
Ida II,	555.6	14.75	81.95	5.74	31.89	.57	3.17
Cecile II,	478.3	15.14	72.41	5.69	27.22	.62	2.97
Betty II,	727.1	13.39	97.36	4.42	32.14	.50	3.64
Totals,	2,299.4	14.49[1]	333.18	5.35[1]	123.07	.56[1]	12.96

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[1] Average percentages obtained by dividing total pounds of solids, etc., by total pounds of milk.

TABLE XXVII. — *Yield of Milk and Milk Ingredients* — Concluded.

Alfalfa Ration.

Cows.	Milk (Pounds).	Solids (Per Cent.).	Solids (Pounds).	Fat (Per Cent.).	Fat (Pounds).	Nitrogen (Per Cent.).	Nitrogen (Pounds).
Red IV,	554.4	14.26	79.06	5.03	27.89	.59	3.27
Ida II,	540.2	14.04	75.84	5.03	27.17	.56	3.03
Cecile II,	490.7	15.26	74.88	5.93	29.10	.59	2.89
Betty II,	714.6	13.69	97.83	4.87	34.80	.56	4.00
Totals,	2,299.9	14.24[1]	327.61	5.17[1]	118.96	.57[1]	13.19
Totals rowen,	5,407.6	–	760.97	–	281.74	–	29.94
Totals alfalfa,	5,568.4	–	767.64	–	278.73	–	31.38

[1] Average percentages obtained by dividing total pounds of solids, etc., by total pounds of milk.

In Experiment IV the alfalfa ration apparently increased the yield of milk 5.2 per cent., while in Experiment V the yield was the same on each ration. The total yield for both experiments was 5,407.6 pounds on the rowen, and 5,568.4 pounds on the alfalfa, or an increase of 3 per cent. in favor of the alfalfa. The rowen ration produced a total yield of 760.97 pounds of solids as against 767.64 pounds for the alfalfa; the total yield of fat was 281.74 pounds on the rowen ration, and 278.73 pounds on the alfalfa; the yield of nitrogen was 29.94 pounds on the rowen ration, and 31.38 pounds on the alfalfa.

The following table shows the amount of milk and milk ingredients produced by *100 pounds of dry matter* derived from each of the two rations: —

TABLE XXVIII. — *Milk and Milk Ingredients produced by 100 Pounds of Dry Matter (Pounds).*

RATION.	Milk.	Solids.	Fat.
Rowen,	93.77	13.19	4.89
Alfalfa,	97.76	13.48	4.89

In case of the volume of milk, and to a less degree in case of the total solids, the yields were rather in favor of the alfalfa ration. The fat percentage, on the other hand, did not keep pace with the increase in the milk yield. Note (Table XXVII) that in Experiment IV, with the rowen ration, the percentage was 5.1 as against 4.82 for the alfalfa ration; and in Experiment V, 5.35 for the rowen ration as against 5.17 for the alfalfa ration. The per cent. of solids not fat was substantially the same in each experiment, namely, 8.66 against 8.64 in the fourth, and 9.14 against 9.07 in the fifth. On the basis of dry matter, the fat yield was the same with each ration.

EXPERIMENT VI.

Alfalfa, English Hay and Grain v. *English Hay and Grain for Milk Production.*

The object of this particular experiment with milch cows was to compare the feeding value of a ration composed of equal parts of alfalfa and English hay, corn-and-cob meal and a little bran (mostly home-grown products) with that of one consisting of English hay, bran, corn-and-cob meal and gluten feed, in order to see whether reasonably satisfactory results could not be secured from the use of alfalfa as a considerable source of protein, in place of purchased protein in the form of bran and gluten feed.

Plan of the Experiment. — Eight cows which had calved during the late summer and autumn were divided into two groups of four each and fed by the reversal method. One group of four received the so-called alfalfa ration at the same time the other four were receiving the English hay and purchased grain ration. In the second half of the trial the feeding was reversed.

TABLE XXIX. — *History of Cows.*

Cows.	Breed.	Age (Years).	Last Calf dropped.	Served.	Milk Yield, Beginning of Trial (Pounds).
Samantha, . .	Grade Holstein, .	8	Sept. 23, 1911	Nov. 7, 1911	-
Fancy II, . .	Grade Jersey, .	4	Oct. 28, 1911	Dec. 10, 1911	26.1
Samantha II, . .	Grade Holstein, .	2	Nov. 1, 1911	Dec. 10, 1911	30.6
Cecile, ...	Pure Jersey, . .	6	Nov. 21, 1911	Mar. 12, 1912	28.9
Red III, ...	Grade Jersey, .	6	Sept. 23, 1911	Nov. 6, 1911	23.7
Daisy II, ...	Grade Jersey, .	2	Nov. 17, 1911	Mar. 25, 1912	20.2
Ida, ...	Pure Jersey, . .	4	Nov. 16, 1911	Feb. 24, 1912	28.0
Betty II, ...	Grade Ayrshire, .	4	Nov. 9, 1911	Jan. 8, 1912	31.1

TABLE XXX. — *Duration of Experiment.*

DATES.	Alfalfa-ration Cows.	English Hay-ration Cows.	Length of Period (Weeks).
Dec. 28, 1911, through Jan. 24, 1912.	Samantha, Fancy II, Samantha II, Cecile.	Red III, Daisy II, Ida, Betty II.	4
Feb. 9 through Mar. 7, 1912,	Red III, Daisy II, Ida, Betty II.	Samantha, Fancy II, Samantha II, Cecile.	4

An interval of fifteen days was allowed between the two periods of the experiment.

Character of Feeds. — The hay was fine and of fair quality, coming from a meadow that had been in grass for a number of years. The alfalfa was grown upon the college grounds, and was of excellent quality. The corn-and-cob meal was excellent, and the bran and gluten feed of average quality.

The method of care and feeding, weighing of the animals and sampling of the feeds and milk were the same as previously described.

TABLE XXXI. — *Analyses of Feeds (Per Cent.).*

FEED.	Water.	Ash.	Crude Protein.	True Protein.	Fiber.	Extract Matter.	Fat.	Totals.
Alfalfa (farm),	11.20	7.25	15.66	11.79	28.62	35.54	1.73	100
Alfalfa (experiment station),	10.14	7.88	16.85	13.79	24.86	38.89	1.38	100
English hay,	9.49	5.58	8.63	7.74	28.45	45.64	2.21	100
Wheat bran,	12.43	6.02	15.46	–	9.68	52.04	4.37	100
Corn-and-cob meal,	16.04	1.28	8.27	–	4.38	66.92	3.11	100
Gluten feed,	9.97	.82	25.74	–	6.64	53.37	3.46	100

TABLE XXXII. — *Total Rations consumed by Each Cow (Pounds).*

ALFALFA RATION.

COWS.	Hay.	Alfalfa.	Bran.	Corn-and-cob Meal.	Gluten Feed.
Samantha,	336	326	56	196	–
Fancy II,	280	278	56	140	–
Samantha II,	336	336	56	168	–
Cecile,	308	304	56	168	–
Red III,	336	329	56	140	–
Daisy II,	224	224	56	140	–
Ida,	280	280	56	168	–
Betty II,	308	298	56	168	–
Totals,	2,408	2,375	448	1,288	–

TABLE XXXII. — *Total Rations consumed by Each Cow (Pounds)* — Concluded.

ENGLISH HAY RATION.

Cows.	Hay.	Alfalfa.	Bran.	Corn-and-cob Meal.	Gluten Feed.
Samantha,	663	–	56	84	112
Fancy II,	553	–	56	56	84
Samantha II,	663	–	56	56	112
Cecile,	586	–	56	84	84
Red III,	762	–	56	84	56
Daisy II,	442	–	56	84	56
Ida,	594	–	56	84	84
Betty II,	604	–	56	84	84
Totals,	4,767	–	448	616	672

TABLE XXXIII. — *Average Daily Ration consumed per Cow (Pounds).*

CHARACTER OF RATION.	Hay.	Alfalfa.	Bran.	Corn-and-cob Meal.	Gluten Feed.
Alfalfa,	10.7	10.6	2	5.8	–
English hay,	21.3	–	2	2.8	3

The above tables show that the average cow on the alfalfa ration consumed 10.6 pounds of alfalfa and 10.7 pounds of hay, or 21.3 pounds of roughage, and in addition, 2 pounds of bran and 5.8 pounds of corn-and-cob meal; while on the hay ration the average cow ate 21.3 pounds of hay, 2 pounds of bran, 2.8 pounds of corn-and-cob meal and 3 pounds of gluten feed. Different cows naturally varied from this average, depending upon their individual requirements. It was a comparison of ration against ration, and not one single feedstuff against another. If similar rations were used by a dairyman, in case of the hay ration he would be obliged to purchase 2 pounds of bran and 3 pounds of gluten feed for each animal; he could produce the hay and the corn-and-cob meal upon the farm. In case of the alfalfa ration he would find it necessary to purchase only the 2 pounds of bran daily, and he could grow the remainder of the ration. In fact, the animals probably would do about as well if the bran were omitted and the corn-and-cob meal correspondingly increased.

TABLE XXXIV. — *Estimated Dry and Digestible Nutrients in Average Daily Rations (Pounds).*

CHARACTER OF RATION.	Dry Matter.	DIGESTIBLE ORGANIC NUTRIENTS.					Nutritive Ratio.
		Protein.	Fiber.	Extract Matter.	Fat.	Total.	
Alfalfa,	25.78	2.30	3.32	9.98	.41	16.01	1 : 6.17
English hay,	26.09	2.07	3.95	9.76	.46	16.24	1 : 7.11

The above results were calculated from actual analyses and average digestion coefficients. The two rations do not vary greatly from each other; the total digestible nutrients are about the same and likewise the extract matter. The amount of digestible fiber in the hay ration is a little higher and the protein a little lower. The daily protein consumption is somewhat higher in the alfalfa ration. One would expect substantially similar results from the two rations. Of the 2.3 pounds of digestible protein in the alfalfa ration, 1.28 pounds, or 55.8 per cent., was from the alfalfa hay, and the balance of 1.02 pounds from the hay and grain. In the hay ration 1.05 pounds, or nearly 50 per cent., of the protein was from the hay, and the balance of 1.02 pounds from the grain.

TABLE XXXV. — *Gain or Loss in Live Weight (Pounds).*

ALFALFA RATION.

	Betty II.	Daisy II.	Ida.	Red III.	Cecile.	Fancy II.	Samantha.	Samantha II.	Total.
Beginning,	827	677	777	873	805	726	1,062	930	-
End,	815	675	772	880	783	708	1,030	900	-
Gain or loss.	—12	—2	—5	+7	—22	—18	—32	—30	—114

ENGLISH HAY RATION.

Beginning,	860	675	827	895	777	725	1,068	942	-
End,	832	657	761	890	793	720	1,040	925	-
Gain or loss,	—28	—18	—66	—5	+16	—5	—28	—17	—151

The cows lost somewhat in weight on both rations.

TABLE XXXVI. — *Yield of Milk and Milk Ingredients.*

ALFALFA RATION.

Cows.	Total Milk (Pounds).	Daily Milk (Pounds).	Solids (Per Cent.).	Solids (Pounds).	Fat (Per Cent.).	Fat (Pounds).
Samantha,	702.2	25.07	15.96	112.07	6.25	43.89
Fancy II,	667.0	23.82	13.23	88.24	4.73	31.55
Samantha II,	829.9	29.64	13.28	110.21	4.48	37.18
Cecile,	762.8	27.24	13.64	104.05	4.85	37.00
Red III,	664.6	23.73	13.60	90.39	5.24	34.83
Daisy II,	516.6	18.45	14.15	73.10	4.93	25.47
Ida,	655.6	23.41	14.59	95.65	5.67	37.17
Betty II,	741.4	26.48	13.41	99.42	4.52	33.51
Totals,	5,540.1	24.73	13.96[1]	773.13	5.06[1]	280.60
ENGLISH HAY RATION.						
Samantha,	766.9	27.39	14.79	113.42	5.69	43.64
Fancy II,	641.5	22.91	13.49	86.54	4.81	30.86
Samantha II,	841.1	30.04	13.28	111.70	4.41	37.09
Cecile,	663.4	23.69	13.81	91.62	5.08	33.70
Red III,	632.7	22.60	13.68	86.55	5.39	34.10
Daisy II,	547.3	19.55	13.56	74.21	4.65	25.45
Ida,	720.0	25.71	14.43	103 90	5.78	41.62
Betty II,	788.6	28.16	13.74	108.35	4.91	38.72
Totals,	5,601.5	25.00	13.86[1]	776.29	5.09[1]	285.18

[1] Average percentages obtained by dividing total pounds of solids and of fat by total pounds of milk.

TABLE XXXVII. — *Average Composition of the Milk (Per Cent.).*

CHARACTER OF RATION.	Total Solids.	Fat.
Alfalfa,	13.96	5.06
English hay,	13.86	5.09

Table XXXVIII. — *Dry and Digestible Matter required for Maintenance and to produce Milk and Milk Ingredients (Pounds).*

Character of Ration.	Dry Matter.			Digestible Nutrients.		
	100 Pounds Milk.	1 Pound Solids.	1 Pound Fat.	100 Pounds Milk.	1 Pound Solids.	1 Pound Fat.
Alfalfa, ...	104.24	7.47	20.57	64.73	4.64	12.78
English hay, ...	104.33	7.56	20.49	64.94	4.69	12.76

The tables showing the yield of milk and milk ingredients, the composition of the milk and the dry and digestible matter required to produce milk all point to the fact that the two rations were equally effective. Only in case of live weight were the results rather against the hay ration.

Experiment VII.

Alfalfa, Corn Stover, Corn-and-cob Meal and Bran v. *English Hay, Corn-and-cob Meal, Gluten Feed and Bran for Milk Production.*

In Experiment VI the feeding effect of a ration composed of one-half English hay, one-half alfalfa, together with a large amount of corn-and-cob meal and a little bran, was compared with a ration of English hay, corn-and-cob meal, gluten feed and bran.

In the present experiment (VII) a ration composed of alfalfa, cut corn stover and a large amount of corn-and-cob meal with a small amount of bran was compared with a ration of English hay and substantially like amounts of corn-and-cob meal, gluten feed and bran.

The question to be answered is, "Can the farmer by growing alfalfa and corn get along without purchasing grain?"

Plan. — Eight cows were used and fed by the usual reversal method. Because the cows calved at different times the eight animals were not all fed between the same dates, but in groups of two.

Table XXXIX. — *History of Cows.*

Cows.	Breed.	Age (Years).	Last Calf dropped.	Served.	Milk Yield, Beginning of Trial (Pounds).
Samantha, . . .	Grade Holstein, .	10	Aug. 26, 1913	Nov. 19, 1913	19.4
Red III, ...	Grade Jersey, .	8	Aug. 23, 1913	Nov. 2, 1913	24.5
Betty, ...	Grade Jersey, .	9	Nov. 23, 1913	Apr. 13, 1914	29.3
Betty II, ...	Grade Ayrshire, .	6	Oct. 18, 1913	Jan. 9, 1914	26.4
Amy, ...	Pure Jersey, . .	6	Dec. 9, 1913	Mar. 14, 1914	30.1
Amy II, ...	Pure Jersey, . .	4	Dec. 17, 1913	Jan. 30, 1914	24.1
Samantha, . . .	Grade Holstein, .	10	Aug. 26, 1913	Nov. 19, 1914	21.0
Red III, ...	Grade Jersey, .	8	Aug. 23, 1913	Nov. 2, 1913	20.5

TABLE XL. — *Duration of Experiment.*

DATES.	Alfalfa, Corn Stover, Corn-and-cob Meal and Bran Ration Cows.	English Hay, Corn-and-cob Meal, Gluten Feed and Bran Ration Cows.	Length of Period (Weeks).
Nov. 19 through Dec. 23, 1913,	Samantha,	Red III,	5
Jan. 3 through Feb. 6, 1914,	Red III,	Samantha,	5
Dec. 24, 1913, through Jan. 27, 1914,	Betty II,	Betty,	5
Feb. 6 through Mar. 12, 1914,	Betty,	Betty II,	5
Jan. 21 through Feb. 24, 1914,	Amy II,	Amy,	5
Mar. 4 through Apr. 7, 1914,	Amy,	Amy II,	5
Feb. 28 through Apr. 3, 1914,	Samantha,	Red III,	5
Apr. 11 through May 15, 1914,	Red III,	Samantha,	5

The care and feeding of the animals, time of weighing and method of sampling feeds and milk were the same as in the previous trial.

Character of Feeds. — The hay was of quite satisfactory quality, timothy predominating; the alfalfa hay was also of average quality. The corn stover was stooked out of doors, and was subject to weather conditions. The corn-and-cob meal was made from corn grown upon the station grounds, while the bran and gluten feed were purchased.

TABLE XLI. — *Analyses of Feeds* (*Per Cent.*).

FEED.	Water.	Ash.	Protein.	Fiber.	Extract Matter.	Fat.
English hay,	11.30	6.04	9.32	29.09	42.50	2.06
Alfalfa hay,	11.90	6.56	14.45	27.99	36.95	2.04
Corn stover,	33.15	4.44	5.96	23.24	32.47	.88
Grain mixture,	11.16	2.92	17.09	7.76	57.32	3.91
Bran,	11.54	5.89	15.58	10.47	51.27	4.80
Corn-and-cob meal,	12.74	1.33	7.94	5.30	69.16	3.27

TABLE XLII. — *Total Rations consumed* (*Pounds*).

	English Hay.	Alfalfa Hay.	Corn Stover.	Grain Mixture.	Bran.	Corn-and-cob Meal.
English hay ration totals,	5,873	–	–	2,240	–	–
Alfalfa ration totals,	–	4,143	1,966	–	684	1,559

TABLE XLIII. — *Average Daily Ration consumed per Cow (Pounds).*

CHARACTER OF RATION.	English Hay.	Alfalfa Hay.	Corn Stover.	Grain Mixture.	Bran.	Corn-and-cob Meal.
English hay, ...	21	-	-	8	-	-
Alfalfa, ...	-	14.8	7	-	2.44	5.57

The "grain mixture" was composed of a mixture, by weight, of 30 parts wheat bran, 35 parts gluten feed and 35 parts corn-and-cob meal.

The above tabulations show that a ration composed of hay and a grain mixture was compared with a ration of alfalfa, some corn stover, a large amount of corn-and-cob meal and a rather limited amount of bran. On the basis of dry matter, the alfalfa ration contained 80 per cent. alfalfa and 20 per cent. corn stover.

In case of the grains, 65 per cent. of the amount fed with the English hay would have to be purchased, and only 30 per cent. of that fed with the alfalfa.

TABLE XLIV. — *Estimated Digestible Nutrients in Average Daily Rations (Pounds).*

CHARACTER OF RATION.	Protein.	Fiber.	Extract Matter.	Fat.	Total.
English hay, ...	1.89	4.32	9.08	.44	15.73
Alfalfa, ...	2.25	3.18	9.54	.38	15.35

The alfalfa ration furnished rather more digestible protein than the English hay ration, although it is believed the latter ration contained all that was needed by the animals. The English hay ration, as nearly as can be estimated, contained rather more total digestible nutrients than the alfalfa ration. This was due to the rather high moisture content of the corn stover fed as a portion of the alfalfa ration. On the basis of digestible nutrients, one would expect slightly better returns from the English hay ration.

TABLE XLV. — *Gain or Loss in Live Weight (Pounds).*

ENGLISH HAY RATION.

	Samantha.	Red III.	Betty II.	Betty.	Amy II.	Amy.	Samantha.	Red III.	Total.
Beginning, ...	1,137	945	870	907	727	830	1,122	955	-
End, ...	1,147	960	892	903	727	785	1,170	955	-
Gain or loss, . .	+10	+15	+22	—4	±	—45	+48	-	+46

TABLE XLV. — *Gain or Loss in Live Weight (Pounds)* — Concluded.

ALFALFA RATION.

	Samantha.	Red III.	Betty II.	Betty.	Amy II.	Amy.	Samantha.	Red III.	Total.
Beginning,	1,090	905	867	870	713	770	1,075	970	-
End,	1,167	915	850	860	700	734	1,075	975	-
Gain or loss,	—23	+10	—17	—10	—13	—36	±	+5	—84

It is evident that the cows gained slightly on the hay and grain ration and lost somewhat on the alfalfa, corn stover and grain ration. Cow Amy was not in very good condition and lost noticeably in weight during both feeding periods.

TABLE XLVI. — *Yield of Milk and Milk Ingredients.*

ENGLISH HAY RATION.

Cows.	Total Milk (Pounds).	Daily Milk (Pounds).	Solids (Per Cent.).	Solids (Pounds).	Fat (Per Cent.).	Fat (Pounds).
Red III,	765.8	21.9	13.61	104.23	4.85	37.14
Samantha,	768.0	21.9	15.73	120.81	5.75	44.16
Betty,	998.3	28.5	13.84	138.16	4.71	47.02
Betty II,	1,000.2	28.6	13.90	139.03	4.73	47.31
Amy,	972.9	27.8	13.81	134.36	5.09	49.52
Amy II,	727.4	20.8	15.15	110.20	5.77	41.97
Red III,	713.2	20.4	14.28	101.84	5.30	37.80
Samantha,	762.3	21.8	14.82	112.97	5.33	40.63
Totals,	6,708.1	24.0[1]	14.33[1]	961.60	5.15[1]	345.55

ALFALFA RATION.

Cows.	Total Milk (Pounds).	Daily Milk (Pounds).	Solids (Per Cent.).	Solids (Pounds).	Fat (Per Cent.).	Fat (Pounds).
Red III,	740.5	21.2	14.40	106.63	5.52	40.88
Samantha,	658.1	18.8	15.54	102.27	5.96	39.22
Betty,	837.4	23.9	13.51	113.13	4.69	39.27
Betty II,	970.1	27.7	14.17	137.46	4.92	47.73
Amy,	835.4	23.9	13.87	115.87	5.10	42.61
Amy II,	789.2	22.6	14.89	117.51	5.59	44.12
Red III,	637.4	18.2	13.96	88.98	5.19	33.08
Samantha,	691.5	19.8	14.98	103.60	5.37	37.13
Totals,	6,159.6	22.0[1]	14.37[1]	885.45	5.26[1]	324.04

[1] Average.

It is very evident that the hay and grain ration gave noticeably larger returns of milk and milk ingredients than did the alfalfa ration. The alfalfa ration produced 8.2 per cent. less milk and 8.6 per cent. less milk solids than did the English hay ration.

The writer is convinced that the milk shrinkage on the alfalfa ration was due largely to the corn stover. While of good quality it was stooked out of doors and brought to the barn every few days and cut fine before being fed. It varied considerably in moisture content, depending upon the weather. If the stover had been brought from the field in November and stored under cover, in all probability more satisfactory results would have been secured.

PART II.

THE VALUE OF CORN BRAN FOR MILK PRODUCTION.

SUMMARY AND SUGGESTIONS.

1. Corn bran contains noticeably less ash, protein and fat, and somewhat more extract or starchy matter, than does wheat bran.

2. Digestion experiments with sheep recently made at this station showed that 80 per cent. of its dry matter was digestible as against 66 per cent. for wheat bran.

3. A definite amount of dry matter contained in a ration composed of hay, gluten feed, ground oats, cottonseed meal and *corn bran* produced, in an average of two experiments, substantially as much milk and milk ingredients as a like amount of dry matter in a ration composed of hay, gluten feed, ground oats, cottonseed meal and *wheat bran.*

4. The gains in live weight were about the same on each ration.

5. Corn bran, if properly combined in a grain ration, is likely to give as satisfactory returns as wheat bran. It may constitute 30 per cent. of the ration, together with 30 per cent. cottonseed or linseed meal, 20 per cent. corn or hominy meal, and 20 per cent. ground oats; or a ration may be combined consisting of 40 per cent. corn bran, 20 per cent. gluten feed, 20 per cent. cottonseed or linseed meal, and 20 per cent. ground oats or barley. A combination of corn bran, gluten feed and corn meal would not be satisfactory because of a deficiency in ash, and because all three constituents would be derived from corn.

THE EXPERIMENT IN DETAIL.

What Corn Bran is. — Corn bran is the hull or skin of the corn kernel, together with a small amount of the germ, and the starchy portion which it is impossible to separate out in the process of manufacture of various corn products, such as starch and glucose. The bran thus obtained was formerly dried and sold by itself, but at present it is more often sold as a constituent of hominy feed or proprietary mixed feeds, or is mixed with corn gluten as a component of gluten feed. It is still sometimes found in the markets of Massachusetts, and has been offered at a reasonable price. It has been shown, by means of experiments[1] conducted at various times, to be well digested by ruminants; its energy value as compared with corn meal at 100 is equal to 82. In the minds of many feeders corn bran is considered a quite inferior product, and at best of doubtful feeding value.

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[1] Massachusetts Experiment Station Bulletin No. 181, p. 316.

Method of conducting the Experiment. — In order to demonstrate its value two feeding experiments with cows were carried out at this station during 1917 and 1918. In one case six and in the other eight cows were fed by the reversal method, for two periods of five weeks each, on a basal ration of hay, gluten feed, ground oats and cottonseed meal.[1] Half of the cows in each case received in addition 4 pounds of *corn bran* during the first periods of the experiments, while the other half received a like amount of *wheat bran*. In the second periods the corn and wheat brans were interchanged. At the outset the cows used in each experiment were as carefully mated in regard to yield of milk and period of lactation as possible, so that the two herds receiving the different rations would vary in general performance but very little. Their names and arrangement may be found in Tables I and II.

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[1] A little cottonseed meal was added to each ration in the second experiment in order to insure against the possible ill effect of having too great a proportion of the grains derived from corn in the corn bran half of the trial.

TABLE I. — *History of Cows.*

EXPERIMENT I.

Cows.	Breed.	Age (Years).	Last Calf dropped.	Served.	Beginning of Trial.		
					Weight (Pounds).	Milk Yield (Pounds).	Fat (Per Cent.).
Peggy,	Grade Jersey,	7	Aug. 9, 1917	- -	755	21	5.20
Samantha II,	Grade Holstein,	8	Aug. 16, 1917	- -	1,090	35	4.20
Colantha II,	Grade Holstein,	3	July 3, 1917	- -	975	27	4.00
Colantha,	Grade Holstein,	3	July 24, 1917	- -	1,190	22	3.40
Samantha III,	Grade Holstein,	4	Aug. 1, 1917	- -	1,140	23	4.40
Samantha IV,	Grade Holstein,	3	July 5, 1917	- -	1,030	27	3.90

EXPERIMENT II.

Cows.	Breed.	Age (Years).	Last Calf dropped.	Served.	Beginning of Trial.		
					Weight (Pounds).	Milk Yield (Pounds).	Fat (Per Cent.).
Red IV,	Grade Jersey,	4	Dec. 2, 1917	- -	800	29	4.70
Colantha,	Grade Holstein,	4	July 24, 1917	Nov. 16, 1917	1,210	18	4.00
Samantha III,	Grade Holstein,	4	Aug. 1, 1917	Nov. 18, 1917	1,140	21	4.70
Samantha IV,	Grade Holstein,	3	July 5, 1917	Jan. 6, 1918	1,050	25	4.25
Fancy III,	Grade Jersey,	9	Dec. 3, 1917	Jan. 9, 1918	900	29	4.55
Peggy,	Grade Jersey,	7	Aug. 9, 1917	Nov. 8, 1917	770	17	6.40
Samantha II,	Grade Holstein,	8	Aug. 16, 1917	Oct. 26, 1917	1,210	30	4.55
Colantha II,	Grade Holstein,	3	July 3, 1917	Oct. 22, 1917	990	26	4.35

As in all feeding experiments, a sufficient preliminary period was allowed at the beginning of each trial for the cows to become accustomed to the rations, and for their alimentary tracts to become emptied of whatever food they may previously have been receiving. For the same reason a transitional period was allowed between the two halves of each experiment. These periods were of at least ten days' duration. The exact dates are given in Table II.

The amounts of hay and grains fed the various cows daily were carefully calculated for each animal, on the basis of its milk and maintenance requirements,[1] and from personal knowledge of the particular animal's appetite.

The general care and management of the animals, as well as the methods of sampling milk, hay and grain, were similar to those already described in the foregoing experiments. The hay which was used in the rations was raised on the experiment station farm, and was of average uniformity and good quality. All the grains were of standard quality. The daily and total amount of each feed per cow may be found in the following table, as well as the average and total amounts per herd: —

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[1] T. L. Haeker, Minnesota Bulletin No. 140, p. 56.

TABLE II. — *Total Amount and Average Daily Amount of Food consumed per Cow and per Ration (Pounds).*

EXPERIMENT I.

Corn Bran Ration.

DATES.	COWS.	HAY.		CORN BRAN.		WHEAT BRAN.		GLUTEN FEED.		GROUND OATS.		COTTONSEED MEAL.	
		Total.	Daily.	Total.	Daily.	Total.	Daily.	Total.	Daily.	Total.	Daily.	Total.	Daily.
Oct. 24 through Nov. 27, 1917, .	Peggy, . .	594.00	16.97[1]	138	3.94	-	-	103.00	2.94	33.00	.94	-	-
	Samantha II, .	840.00	24.00	140	4.00	-	-	157.50	4.50	87.50	2.50	-	-
	Colantha II, .	630.00	18.00	140	4.00	-	-	140.00	4.00	70.00	2.00	-	-
Dec. 8, 1917, through Jan. 11, 1918,	Colantha, . .	735.00	21.00	140	4.00	-	-	52.50	1.50	87.50	2.50	-	-
	Samantha III, .	770.00	22.00	140	4.00	-	-	105.00	3.00	70.00	2.00	-	-
	Samantha IV,[2] .	735.00	21.00	140	4.00	-	-	105.00	3.00	70.00	2.00	-	-
Totals, ...	. . . . .	4,304.00	-	838	-	-	-	663.00	-	418.00	-	-	-
Average, ...	. . . . .	-	20.50	-	3.99	-	-	-	3.16	-	1.99	-	-

Wheat Bran Ration.

DATES.	COWS.	HAY.		CORN BRAN.		WHEAT BRAN.		GLUTEN FEED.		GROUND OATS.		COTTONSEED MEAL.	
		Total.	Daily.	Total.	Daily.	Total.	Daily.	Total.	Daily.	Total.	Daily.	Total.	Daily.
Oct. 24 through Nov. 27, 1917, .	Colantha, . .	735.00	21.00	-	-	140	4	52.50	1.50	87.50	2.50	-	-
	Samantha III, .	770.00	22.00	-	-	140	4	105.00	3.00	70.00	2.00	-	-
	Samantha IV, .	735.00	21.00	-	-	140	4	105.00	3.00	70.00	2.00	-	-
Dec. 8, 1917, through Jan. 11, 1918,	Peggy, . .	594.00	16.97	-	-	140	4	105.00	3.00	35.00	1.00	-	-

	Samantha II,	840.00	24.00	-	-	140	4	157.50	4.50	87.50	2.50	-	-
	Colantha II,[2]	630.00	18.00	-	-	140	4	140.00	4.00	70.00	2.00	-	-
Totals,		4,304.00	-	-	-	840	-	665.00	-	420.00	-	-	-
Average,		-	20.50	-	-	-	4	-	3.17	-	2.00	-	-

Experiment II.

Corn Bran Ration.

Feb. 20 through Mar. 26, 1918,	Red IV,	697.00	19.92	140	4.00	-	-	-	-	87.50	2.50	105.00	3.00
	Colantha,	770.00	22.00	140	4.00	-	-	-	-	70.00	2.00	52.50	1.50
	Samantha III,	770.00	22.00	140	4.00	-	-	52.50	1.50	35.00	1.00	52.50	1.50
	Samantha IV,	732.55	20.93	140	4.00	-	-	52.50	1.50	70.00	2.00	52.50	1.50
Apr. 6 through May 10, 1918,	Fancy III,	722.40	20.64	140	4.00	-	-	-	-	87.50	2.50	105.00	3.00
	Peggy,	593.60	16.96	140	4.00	-	-	35.00	1.00	35.00	1.00	52.50	1.50
	Samantha II,	840.00	24.00	140	4.00	-	-	122.50	3.50	87.50	2.50	35.00	1.00
	Colantha II,	665.00	19.00	140	4.00	-	-	105.00	3.00	52.50	1.50	35.00	1.00
Totals,		5,790.55	-	1,120	-	-	-	367.50	-	525.00	-	490.00	-
Average,		-	20.68	-	4.00	-	-	-	1.31	-	1.88	-	1.75

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[1] When a decimal appears in the daily amount of hay fed it signifies an amount left unconsumed by the animal in question, and that this average daily amount wasted has been deducted in order to get the amount actually consumed daily.

[2] Due to sickness, cows Samantha IV and Colantha II were given different dates for the second half of the first experiment, as follows: Samantha IV from December 17 to January 21; Colantha II from December 31 to February 4.

TABLE II. — *Total Amount and Average Daily Amount of Food consumed per Cow and per Ration (Pounds)* — Concluded.

EXPERIMENT II — *Concluded.*

Wheat Bran Ration.

DATES.	COWS.	HAY.		CORN BRAN.		WHEAT BRAN.		GLUTEN FEED.		GROUND OATS.		COTTONSEED MEAL.	
		Total.	Daily.	Total.	Daily.	Total.	Daily.	Total.	Daily.	Total.	Daily.	Total.	Daily.
Feb. 20 through Mar. 26, 1918,	Fancy III,	726.60	20.76	-	-	140	4	-	-	87.50	2.50	105.00	3.00
	Peggy,	586.60	16.76	-	-	140	4	35.00	1.00	35.00	1.00	52.50	1.50
	Samantha II,	835.50	23.87	-	-	140	4	122.50	3.50	87.50	2.50	35.00	1.00
	Colantha II,	665.00	19.00	-	-	140	4	105.00	3.00	52.50	1.50	35.00	1.00
Apr. 6 through May 10, 1918,	Red IV,	698.60	19.96	-	-	140	4	-	-	87.50	2.50	105.00	3.00
	Colantha,	770.00	22.00	-	-	140	4	-	-	70.00	2.00	52.50	1.50
	Samantha III,	770.00	22.00	-	-	140	4	52.50	1.50	35.00	1.00	52.50	1.50
	Samantha IV,	735.00	21.00	-	-	140	4	52.50	1.50	70.00	2.00	52.50	1.50
Totals,		5,787.30	-	-	-	1,120	-	367.50	-	525.00	-	490.00	-
Average,		-	20.67	-	-	-	4	-	1.31	-	1.88	-	1.75

TABLE III. — *Analyses of Feeds (Per Cent.).*

EXPERIMENT I.

FEED.	Average Moisture.[1]	Dry Matter.[1]	DRY MATTER.				
			Ash.	Protein.	Fiber.	Extract Matter.	Fat.
Hay,	11.63 10.25[2]	88.37 89.75[2]	6.35	8.28	32.39	50.32	2.66
Corn bran,	12.90 11.81	87.10 88.19	1.05	7.76	11.79	78.19	1.21
Wheat bran,	11.33 10.97	88.67 89.03	7.13	17.23	10.23	60.90	4.51
Gluten feed,	10.44 10.30	89.56 89.70	4.72	30.52	7.13	54.78	2.85
Ground oats,	11.16 10.23	88.84 89.77	3.88	11.52	11.67	67.71	5.22

EXPERIMENT II.

FEED.	Average Moisture.[1]	Dry Matter.[1]	Ash.	Protein.	Fiber.	Extract Matter.	Fat.
Hay,	11.34 10.58	88.66 89.42	5.88	7.83	33.68	50.35	2.26
Corn bran,	12.62 11.59	87.38 88.41	1.31	7.36	12.62	77.36	1.35
Wheat bran,	11.55 11.99	88.45 88.01	7.05	16.31	11.25	59.90	5.49
Gluten feed,	9.42 9.29	90.58 90.71	3.87	29.66	8.17	55.49	2.81
Ground oats,	10.66 10.39	89.34 89.61	3.72	11.99	11.88	66.91	5.60
Cottonseed meal,	9.60 9.11	90.40 90.89	6.23	38.64	13.10	34.77	7.26

[1] The two figures in each case represent the average of three samples taken in each half of the trials.

[2] In case of cows Samantha IV and Colantha II special samples of hay had to be taken during the second half of the experiment for moisture determinations, and the figures derived are as follows: Samantha IV, moisture 10.38, dry matter 89.62; Colantha II, moisture 9.86, dry matter 90.14.

The variations in composition of the hay and grain used were comparatively slight. The average analyses of the corn and wheat brans used in the two experiments compare as follows on the dry-matter basis: —

TABLE IV. — *Average Analyses of the Corn and Wheat Brans (Per Cent.).*

	Ash.	Protein.	Fiber.	Extract Matter.	Fat.
Corn bran,	1.18	7.56	12.20	77.78	1.28
Wheat bran,	7.09	16.77	10.74	60.40	5.00

Wheat bran contains more ash, protein and fat, and noticeably less extract or starchy matter, than does the corn bran. In using corn bran as a component of a dairy ration these differences, particularly the ash and protein, would have to be given consideration.

By applying the percentages of dry matter of the various feeds as given in Table III to the amounts fed (Table II), the amounts of dry matter fed can easily be obtained. Only the totals for the herds and the average per animal for each herd are given in Table V.

TABLE V. — *Total Amount and Average Daily Amount of Dry Matter consumed (Pounds).*

EXPERIMENT I.

Corn Bran Ration.

	Hay.	Corn Bran.	Wheat Bran.	Gluten Feed.	Ground Oats.	Cotton-seed Meal.
Total,	3,834	733	-	593	374	-
Daily average,	18.26	3.50	-	2.83	1.78	-

Wheat Bran Ration.

	Hay.	Corn Bran.	Wheat Bran.	Gluten Feed.	Ground Oats.	Cotton-seed Meal.
Total,	3,840	-	747	596	375	-
Daily average,	18.26	-	3.55	2.84	1.79	-

EXPERIMENT II.

Corn Bran Ration.

	Hay.	Corn Bran.	Wheat Bran.	Gluten Feed.	Ground Oats.	Cotton-seed Meal.
Total,	5,155	984	-	333	444	470
Daily average,	18.42	3.52	-	1.19	1.59	1.68

Wheat Bran Ration.

	Hay.	Corn Bran.	Wheat Bran.	Gluten Feed.	Ground Oats.	Cotton-seed Meal.
Total,	5,153	-	988	333	444	469
Daily average,	18.41	-	3.53	1.19	1.59	1.68

During the two experiments the total amount of dry matter consumed by the cows receiving the corn bran ration was 12,920 pounds, while the cows receiving the wheat bran ration consumed substantially the same, or 12,945 pounds. Of these totals, 1,717 pounds represented corn bran and 1,735 pounds wheat bran. For convenience the average daily amounts of dry matter consumed per cow in the two rations of both experiments are here tabulated.

TABLE VI. — *Average Daily Amount of Dry Matter consumed per Cow (Pounds).*

RATION.	Hay.	Corn Bran.	Wheat Bran.	Gluten Feed.	Ground Oats.	Cotton-seed Meal.[1]
Corn bran, . . .	18.34	3.51	-	2.01	1.73	1.59
Wheat bran, . . .	18.34	-	3.54	2.02	1.74	1.59

An application of the percentage composition of each feed as given in Table III to the above figures would give the amounts of protein, fat, fiber, etc., each ration contained, and this in turn multiplied by average digestion coefficients[2] would give the approximate digestible nutrients in each ration.

TABLE VII. — *Estimated Dry and Digestible Nutrients in Average Daily Rations (Pounds).*

CHARACTER OF RATION.	Dry Matter.	DIGESTIBLE NUTRIENTS.					Nutritive Ratio.[3]
		Protein.	Fiber.	Extract Matter.	Fat.	Total.	
Corn bran, . .	26.39	1.92	4.12	9.75	.44	16.23	1 : 7.72
Wheat bran, . .	26.42	2.23	4.01	9.16	.52	15.92	1 : 6.40

It will be seen that the dry and digestible matter consumed in each ration was almost identical. The digestible protein contained in the corn bran ration was some 14 per cent. less than that in the wheat bran ration. It is believed, however, that a surplus remained after making the usual allowance for maintenance and milk requirements.

---

[1] Used in Experiment II only.

[2] Coefficients used were the results of determinations made with sheep. Lack of space prohibited printing them here.

[3] Fat taken to equal 2.2 times carbohydrates.

TABLE VIII. — *Yield of Milk and Milk Ingredients.*

EXPERIMENT I.

Corn Bran Ration.

DATES.	COWS.	Milk (Pounds).	Solids (Per Cent.).	Solids (Pounds).	Fat (Per Cent.).	Fat (Pounds).
Oct. 24 through Nov. 27, 1917.	Peggy, . .	559.7	16.20	90.67	6.95	38.90
	Samantha II, .	981.7	12.99	127.52	4.61	45.26
	Colantha II, .	797.6	13.12	104.65	4.43	35.33
Dec. 8, 1917, through Jan. 11, 1918.	Colantha, . .	633.0	12.63	79.95	4.11	26.02
	Samantha III, .	691.4	13.82	95.55	4.90	33.88
	Samantha IV,[1] .	896.9	12.93	116.00	4.18	37.50
Totals, . . .	. . . . .	4,560.3	–	614.34	–	216.89
Average,[2] . . .	. . . . .	–	13.47	–	4.76	–

Wheat Bran Ration.

DATES.	COWS.	Milk (Pounds).	Solids (Per Cent.).	Solids (Pounds).	Fat (Per Cent.).	Fat (Pounds).
Oct. 24 through Nov. 27, 1917.	Colantha, . .	601.2	12.45	74.85	4.19	25.19
	Samantha III, .	699.4	13.56	94.84	4.89	34.20
	Samantha IV, .	837.4	12.59	105.43	4.15	34.75
Dec. 8, 1917, through Jan. 11, 1918.	Peggy, . .	605.6	16.17	97.93	6.80	41.18
	Samantha II, .	1,058.1	13.01	137.66	4.53	47.93
	Colantha II,[1] .	871.6	13.12	114.35	4.33	37.74
Totals, . . .	. . . . .	4,673.3	–	625.06	–	220.99
Average,[2] . . .	. . . . .	–	13.38	–	4.73	–

EXPERIMENT II.

Corn Bran Ration.

DATES.	COWS.	Milk (Pounds).	Solids (Per Cent.).	Solids (Pounds).	Fat (Per Cent.).	Fat (Pounds).
Feb. 20 through Mar. 26, 1918.	Red IV, . .	945.1	13.65	129.01	5.07	47.92
	Colantha, . .	584.8	12.63	73.86	4.03	23.57
	Samantha III, .	672.4	13.68	91.98	4.66	31.33
	Samantha IV, .	851.3	12.82	109.14	4.10	34.90
Apr. 6 through May 10, 1918.	Fancy III, .	889.0	12.42	110.41	4.35	38.67
	Peggy, . .	496.9	15.28	75.93	6.21	30.86
	Samantha II, .	886.6	12.91	114.46	4.43	39.28
	Colantha II, .	675.9	13.67	92.40	4.59	31.02
Totals, . . .	. . . . .	6,002.0	–	797.19	–	277.55
Average,[2] . . .	. . . . .	–	13.28	–	4.62	–

---

[1] See footnote, Table II.

[2] Average obtained by dividing total pounds of solids and fat by total pounds of milk.

EXPERIMENT II — *Concluded.*

Wheat Bran Ration.

DATES.	COWS.	Milk (Pounds).	Solids (Per Cent.).	Solids (Pounds).	Fat (Per Cent.).	Fat (Pounds).
Feb. 20 through Mar. 26, 1918.	Fancy III, .	933.3	12.61	117.69	4.42	41.25
	Peggy, . .	552.0	15.20	83.90	6.24	34.44
	Samantha II, .	1,004.8	12.84	129.02	4.36	43.81
	Colantha II, .	765.8	13.33	102.08	4.31	33.01
Apr. 6 through May 10, 1918.	Red IV, . .	832.8	13.68	113.93	5.02	41.81
	Colantha, . .	463.9	12.99	60.26	4.36	20.23
	Samantha III, .	633.9	13.63	86.40	4.78	30.30
	Samantha IV, .	828.9	12.78	105.93	4.18	34.65
Totals, . . .	. . . . .	6,015.4	–	799.21	–	279.50
Average,[1] . . .	. . . . .	–	13.29	–	4.65	–

[1] Average obtained by dividing total pounds of solids and fat by total pounds of milk.

The total milk produced in the two experiments on the corn bran ration was 10,562.3 pounds, and 10,688.7 pounds on the wheat bran ration, an increase of 1.19 per cent. in favor of the latter. The total solids produced on the corn bran ration amounted to 1,411.5 pounds as against 1,424.3 pounds for the wheat bran. The corn bran ration produced 494.4 pounds of fat as against 500.5 pounds on the wheat bran ration, an increase of 1.3 per cent.

TABLE IX. — *Gain or Loss in Live Weight (Pounds).*

RATION.	EXPERIMENT I.		EXPERIMENT II.		Totals.
	Gain.	Loss.	Gain.	Loss.	
Corn bran, ...	93	32	86	18	+129
Wheat bran, ...	91	8	106	50	+139

A slight gain was made on each ration.

BULLETIN No. 187 NOVEMBER, 1918

MASSACHUSETTS AGRICULTURAL EXPERIMENT STATION

CLARIFICATION OF MILK

PART I

By CHARLES E. MARSHALL and E. G. HOOD

Together with

Lieutenant R. C. Avery, S. G. Mutkekar, Lieutenant William L. Payne, Mary L. Chase, Harry A. Cheplin, Louise Hompe, John E. Martin, Conrad H. Lieber, James Neill, Louis P. Hastings, John Yesair. The independent work of Lieutenant E. L. Davies has been included

Our purpose has been to ascertain, if possible, the real significance of clarification of milk

Requests for bulletins should be addressed to the
Agricultural Experiment Station
Amherst, Mass.

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PUBLICATION OF THIS DOCUMENT
APPROVED BY THE
SUPERVISOR OF ADMINISTRATION.

BULLETIN No. 187.

DEPARTMENT OF MICROBIOLOGY.

CLARIFICATION OF MILK.

PART I.

I. INTRODUCTION.

THE SIGNIFICANCE OF THE CLARIFIER.

The use of the clarifier has been an outgrowth of the employment of the "separator" in an attempt to clarify or purify milk. Since the function of the "separator" is to remove the fat from milk, the addition of a new function to this machine presented complications not easily overcome in a single machine, for as improvement takes place in the primary purpose of the separator, retrogression may be instituted in the secondary, as in this case, — the clarification or purification of milk. The separation of fat from milk is not desired in clarification, yet it is desirable to accomplish what the separator also succeeds in doing in part, — the removal of foreign and unwholesome elements so far as this is possible. A single-purposed machine is susceptible of higher development simply because it does not have to compromise with other and foreign purposes. Accordingly, there is good reason, as a basis, for endeavoring to perfect a machine which will perform the single function of clarification in its highest degree.

WHAT IS CLARIFICATION?

It is the work of this comparatively new machine, known as a clarifier, which has been subjected to careful study in this laboratory. Its function, not its mechanism, has been studied.

Milk is poured into the machine from which it emerges as milk. In its passage through it has lost that substance which adheres to the bowl of the machine, — the slime. The problem before us, therefore, takes this form: *What is the slime, and in its removal from milk has it improved or injured the milk?* The fullest answer which can be given at this time is the substance of this continued thesis. The categorical reply to this question cannot be given till the close of this laboratory's studies, which, it is to be hoped, may eventually have fairly covered the field comprehensively as well as quite intensively.

The present attitude toward the clarifier is reflected by the Commission on Milk Standards[1] which offers a status on clarification. Summing up the points bearing upon milk purification by the clarifier are found these views: —

Favorable: —

(*a*) It removes visible dirt.
(*b*) It removes inflammatory products, including many of the causative germs.
(*c*) It performs the work of the strainer, but in a much more efficient manner.

Against: —

(*a*) It removes visible dirt, but not all disease-producing germs, and hence misleads the consumer as to the real purity of the milk.
(*b*) It does not remove urine or the soluble portion of feces; nevertheless the milk appears clean.
(*c*) It adds another process requiring the handling of the milk, complicating the situation.
(*d*) It largely destroys the value of the dirt test, though no more so than good straining.
(*e*) It breaks up clumps of bacteria and distributes them through the milk.
(*f*) The exact nature of the material removed is not yet fully understood.

The essence of the above assertions is found in the bewildering effect it produces on the mind of a critical reader, for it both asserts and does not assert. When the summary concludes thus: "The exact nature of the material removed is not yet fully understood," it neutralizes the first effect produced and causes a fog to settle on the rather precocious opinions preceding. It is unfortunate that the reader is left to speculate concerning the realities which actually lie submerged beneath this opalescent atmosphere. It is fitting, therefore, to analyze these statements, not exhaustively, but a little more closely, just for the purpose of indicating their looseness.

Putting several of these statements together, the thought is thrown into one or two channels: —

(*a*) It removes visible dirt.

(*b*) It performs the work of a strainer, but in a much more efficient manner.

(*c*) It removes visible dirt, but not all disease-producing germs, and hence misleads the consumer as to the real purity of the milk.

(*d*) It largely destroys the value of the dirt test, though no more so than good straining.

In other words, it removes visible dirt more effectively than any strainer. "Confusing the consumer," "the total elimination of organisms," and "the effect on a test" have no relation to its claim. It may be said, too, that straining of milk must be as reprehensible in misleading the consumer as clarifying, for does it not prepare the consumer for a more sightly product? Yet straining is upheld. The authors feel confident that such assertions as the above will mislead the reader.

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[1] U. S. Public Health Service, Public Health Reports, Vol. 2, No. 7, p. 17.

Again, "it does not remove *all* the disease-producing organisms." It would be a rare centrifuging machine which would claim such a function as eliminating *all pathogenic* micro-organisms, in the light of what is known about centrifuging out such forms. Selective elimination of this nature savors of the superhuman at present, and implies more than is possible. The clarifier is the product of human effort.

"It destroys the value of the dirt test." This is rated as an unfavorable quality, yet is considered favorable in the case of straining. One might ask whether it is desirable to remove as much dirt as possible, or allow it to remain simply to make the dirt test, occasionally applied, effective?

If the authors were to sum up these statements as they stand, they must conclude that the clarifier is a far more efficient strainer, which is allowed, apparently, than any now in use.

A criticism of the clarifier, very peculiar because of its subtle nature, is introduced: —

"(*b*) It does not remove urine or the soluble portion of feces; nevertheless the milk appears clean." The implication here is far-reaching, for the reader might think that there is such a machine or device, on the one hand or on the other, and that such a claim is made for the clarifier or a centrifuge. Why such an assertion is left in its baldness for lay readers to digest the writers cannot understand. Does any device accomplish it, does even pasteurization of milk, which is a sort of panacea advocated by this commission for all milk trouble, overcome what is intimated? That such products exist even in the best of milk, in an infinitesimal degree, cannot be denied, but it seems a strange assertion in connection with a review of clarification. Why not explain?

Here is another very interesting assertion (this is properly made): "(*e*) It breaks up clumps of bacteria and distributes them through the milk." This is well-founded, but what is the result? The need of an answer to this is apparent and it should accompany the statement. Does the commission know? In a general way, how often is such a reason given?

"(*c*) It adds another process requiring the handling of the milk, complicating the situation." Here, too, is one of those statements which are so commonly brought forth to "clinch" an argument. Has man ever hesitated to utilize a new device, when such a device, so far as he can determine, improves the product, even if it does entail a new movement? It corresponds very closely with the exclamation of a certain writer who had done no particular work with the clarifier, and who closed his review with, "What next?"

The authors have perhaps colored this very brief analysis too highly by specific selections, but not without a purpose. They have not even done it to criticize, although criticism may be merited in a way. The object has been to bring conspicuously before the reader the confused condition of minds and the lack of knowledge as well as the existence of certain substrata of prejudice relevant to a new device (the clarifier) designed to meet a specific demand which had been fostered by the frequent use of another device (the separator) for clarification.

On the other hand, criticism could be easily framed from a review of literature of manufacturing firms which has for its purpose the setting forth of the merits of the clarifier. While the specific statements have a modicum of truth and a basis in fact, the reader is left to deduce a quantitative estimate which is very misleading. There exists a sinister purpose beneath the surface which is not commendable. How, for instance, is the reader to gather the significance of a photograph of slime deposit when he knows nothing about its relation to the milk? Is he to infer that milk which may be highly infectious to man is rendered safe when passed through a clarifier? Such a statement and many others, by inference, are highly reprehensible, and should not be tolerated by intelligent men. If the clarifier cannot prove its value *per se*, then it is rightly questioned and should be weighed in the balance of exacting scrutiny. Let this new contribution be judged by its work stated in concrete and sane speech. It is only fair to the public to have sanitarians and manufacturers alike deal frankly and honestly with such matters as clarification.

Such statements need study, and some of them should not have been written before a careful investigation had been made.

Clarification aims to assist in the purification of milk. Does it do it or does it not, and to what degree? This is the definite goal toward which the work of this laboratory has been directed. At the start it is frankly allowed that the best way to secure pure milk is to have a sound cow and obtain the milk free from dirt and disease contamination. This is a recommendation difficult to execute. Human knowledge and performance are weak. It seems impracticable to many minds. The clarifier is offered as a means to assist in accomplishing what man as a machine fails to do. The performance of the clarifier is bound up in what is removed in the slime, and in how the removal of this slime affects the milk from which it has been eliminated.

II. SLIME.

Slime is that material which is removed from the milk during the process of clarification, and which adheres to the bowl of the clarifier. It consists, speaking in a general manner, of the so-called leucocytes or epithelial cells of milk, or corpuscular elements of milk, so-called fibrin which exists in milk in the form of microscopic shreds, traces of casein, traces of fat, traces of milk sugar, inflammatory products such as garget at times, bacteria, yeasts, molds which succeed in entering the milk, and the insoluble dirt which may be present in the milk, or other foreign insoluble particles which may find their way into the milk, — in short, anything which may be suspended and not in solution in milk and which will respond to centrifugalization.[1]

---

[1] A clarifier is a centrifuge, accordingly these terms are employed interchangeably as well as centrifugalization and clarification.

These substances which make up the slime will be subjected to individual scrutiny as progress is made.

AMOUNT OF SLIME REMOVED.

The amount of slime removed by the clarifier depends upon many factors, as may be guessed from its component parts. Besides the influence of the constituents of milk, temperature, acidity or age of milk, individuality of the cow, the condition of the machine, the number of revolutions of the bowl, and probably many other factors determine the amount of slime within its total limitations or the amount which is possible within a given amount of milk. Then, too, as clarification proceeds, the character — perhaps more specifically and accurately the consistency — of the slime changes, which is doubtless attributable to the mechanical action of the clarifier.

Determination of the Weight of Slime.

As a rule, in literature moist weight is employed to report the amount of slime. If conditions were identical when clarifying, the clarifiers the same, the amount of milk passed of the same measurement, then possibly a fairly representative lot of determinations could be established. This seems very difficult, however, as will be gathered later. Owing to this fluctuation in the moisture content, it is essential that the moisture be eliminated to constant weight before comparisons can be satisfactorily made and a true interpretation of the amount established. For many purposes this additional labor may be avoided and the moist weight will serve. Accordingly, it was found desirable early in the work to establish the variations in the determinations of the amount of slime from different sources, since difficulty was met in the interpretation of results when based upon moist weight alone. The determinations furnished are based on clarification of milk at the same temperature, the same milk and the same age of milk, the use of the same machine, the same number of revolutions per minute,—in short, the same methods and procedures throughout. It is therefore a test of methods and procedures, and has its very important bearing upon slime determination. The weights are always recorded as moist or dry weight.

TABLE I. — *A Determination of the Weight of Slime under Moist and Dry Conditions.*

[Thirty pounds of milk used for each sample; milk was held at 70° F.]

SAMPLE.	Number of Test.	SLIME.			
		MOIST WEIGHT IN —		DRY WEIGHT IN —	
		Grams.	Per Cent. of Milk.	Grams.	Per Cent. of Milk.
I,	1	6.7100	.049	1.6217	.011
	2	6.5905	.048	1.6017	.011
II,	1	5.6425	.041	1.3136	.009
	2	5.7036	.041	1.3836	.010
III,	1	6.7544	.049	1.6317	.011
	2	6.4483	.047	1.5180	.011
IV,	1	4.4049	.032	1.1150	.008
	2	4.0133	.029	.9540	.007
V,	1	4.8775	.035	1.1551	.008
	2	4.6215	.033	1.2510	.009
VI,	1	5.1382	.037	1.3598	.009
	2	5.0012	.036	1.2746	.009
VII,	1	5.8314	.042	1.3770	.010
	2	6.4810	.047	1.6286	.011
	3	4.8073	.035	1.0482	.007
	4	4.3109	.031	.9965	.007
VIII,	1	6.6093	.048	1.5088	.011
	2	6.7741	.049	1.6839	.012
IX,	1	5.8910	.043	1.4629	.010
	2	6.0158	.044	1.4715	.010
X,	1	4.5792	.033	1.1793	.008
	2	4.2663	.031	1.0558	.007
	3	4.8683	.035	1.2783	.009
	4	4.5678	.033	1.1552	.008
XI,	1	6.2538	.045	1.5084	.008
	2	6.0309	.044	1.4379	.010
	3	6.1542	.045	1.4725	.010
	4	6.0529	.044	1.4218	.010
XII,	1	5.3230	.039	1.2436	.009
	2	5.3092	.038	1.2552	.009
XIII,	1	4.6834	.034	1.2756	.009
	2	4.6892	.034	1.2417	.009
	3	4.7127	.034	1.2526	.009
XIV,	1	4.6806	.034	1.2756	.009
	2	4.7212	.034	1.2526	.009
	3	4.5300	.034	1.3900	.010
XV,	1	7.1353	.052	1.9734	.014
	2	7.0018	.051	1.9546	.014
XVI,	1	7.0210	.051	1.9232	.014
	2	7.1330	.052	2.0017	.014
XVII,	1	5.8702	.043	1.3654	.010
	2	5.8702	.043	1.3821	.010

Literature is quite consistent in the amount of slime given off in clarification. The necessity for constant weight is evident from the preceding table if exact determinations for comparison are to be made.

The Determinations of Others. — Bahlman[1] says the weight of material deposited in the clarifier from 725 gallons of milk was 2½ pounds. As an average, then, 1 gallon of milk yielded 1.6 grams of moist sludge (.044 per cent.) equivalent to .6 gram (.01 per cent.) of dried material.

In his "Studies on the Clarification of Milk," Hammer[2] gives the following amounts of slime secured from different lots of milk: —

TABLE II. — *Amounts of Slime obtained from Different Lots of Milk (Hammer).*

Pounds of Milk Clarified.	Amount of Slime Deposited in Cubic Centimeters.[3]	Per Cent. of Slime Removed.	Pounds of Milk Clarified.	Amount of Slime Deposited in Cubic Centimeters.[3]	Per Cent. of Slime Removed.
635	70	.024	953	65	.015
837	125	.032	1,249	125	.022
725	90	.027	1,147	250	.048
1,150	70	.013	1,356	125	.020
918	70	.016	1,241	100	.017
1,169	45	.008			

There has been contributed to this theme the experience of McInerney:[4] —

TABLE III. — *Amount of Slime obtained from Different Quantities of Milk (McInerney).*

Experiment.	Milk used (Ounces).	Slime obtained (Ounces).	Per Cent. of Slime.
1,	89,088	5.64	.0063
2,	82,964	7.65	.0092
3,	87,680	6.98	.0080
4,	88,960	6.49	.0073
5,	89,088	6.80	.0076
6,	84,480	12.62	.0149
7,	84,480	8.25	.0091
8,	84,480	6.45	.0076

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[1] Bahlman, Clarence: Milk Clarifiers. Am. Jour. of Public Health, 1916, Vol. VI, No. 8, p. 856.

[2] Hammer, B. W.: Agricultural Experiment Station, Iowa State College of Agriculture and Mechanic Arts. Research Bulletin No. 28, January, 1916.

[3] This appears to be moist slime measured in cubic centimeters.

[4] McInerney, T. J.: Clarification of Milk. Cornell University Agricultural Experiment Station. Bulletin No. 389, April, 1917, p. 496.

The author states: "After all the milk had been passed through, the machine was taken apart and the amount of slime deposited on the walls was carefully removed, placed in a bottle, and weighed." He does not say whether it is moist weight or dry weight.

It is apropos that the extensive work of Lieutenant Davies[1] be inserted here, inasmuch as it contributes very suggestive data. The authors present it exactly as it was found. The results secured furnish information upon slime-yield nowhere else to be found, and it has these advantages: The amount of slime is measured from milk of individual cows, and where it has been possible to point out abnormalities this has been done. In the interpretation of Lieutenant Davies' results it will be well to keep in mind that very small amounts of milk were used, which usually leads to a high percentage of moisture in the slime; that the weight is moist weight which is subject to great fluctuation; and that the diagnosis of abnormalities appears crude because no intimate study has been made. Yet these data are far more suggestive of what is involved in the process of clarification, so far as slime production is concerned, than can be gleaned from almost any other source.

CLARIFICATION OF CERTIFIED MILK (DAVIES).

Methods.

De Laval Clarifier No. 95 was used in this work, its capacity being well suited for the work, the quantities of milk from each cow being very variable and usually small. In place of the tank supplied with the clarifier a funnel was fitted so that given quantities could be easily measured. At the same time there was the advantage that every bit of milk could be passed through the bowl without rinsing with water; also no particles of dirt could remain on the side. While the latter was of no consequence with the certified milk, it does make a difference with the ordinary market milk.

Three bowls were used; this allowed plenty of time for washing and sterilizing them. The bowl shell was weighed while quite dry before the test. The milk was clarified immediately after being drawn, 4 quarts being used where possible; if less than 4 quarts, then all the milk was clarified. The bowl was allowed to run down itself, any attempt to stop it quickly seemed to shake the slime film off on to the discs, and weighing was impossible. The bowl was wiped dry and weighed; the amount of slime was calculated in per cent. of milk clarified.

The cows were tested as often as circumstances would allow. No attempt was made to keep any definite order, it being found best to test whenever the milk and clarifier were ready together; in this way no inconvenience due to waiting was caused the milker.

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[1] Lieut. E. L. Davies was connected with this department as a graduate assistant at the time this work was done. It was, however, executed independently of this bulletin and as a minor thesis. He was majoring in microbiology and pursuing dairying as one of his minors in his graduate work. He became restless when the war opened and tried many times to enter the Canadian service, but was refused on account of physical disability. He was invited by Prof. Dan H. Jones of the Ontario Agricultural College to become a member of the bacteriological staff. Remaining there for a period, and removing his physical disability at the same time, he again became restless for active service. He was accepted into the officers' school. After several months of training on this side, together with local service, he was sent to France. He experienced active service in the trenches at once. Within six weeks he was shot down by Germans whom he was making prisoners.

In the table on pages 163–175 the breed of the cow is designated by the initial letter of the breed, a prefix "R" designating "registered," prefix "G" designating "grade." Example, G. G., — Grade Guernsey.

Ages are given in years and months approximately. Weeks in lactation calculated from the first week of lactation.

Number of tests made, 440, with 74 different cows.

1 cow	tested 11 times.
1 cow	tested 10 times.
5 cows	tested 9 times.
14 cows	tested 8 times.
13 cows	tested 7 times.
12 cows	tested 8 times.
9 cows	tested 5 times.
6 cows	tested 4 times.
6 cows	tested 3 times.
5 cows	tested twice.
2 cows	tested once.

Sixty-five, or 14.7 per cent., showed bloody slime. Seventy-four, or 16.8 per cent., gave .1 per cent. slime or over. Average slime for 440 tests, .067 per cent.

Cow.	Date.	Weeks in Lactation.	Milk (Pounds).	Slime (Per Cent.).	Remarks.
No. 1. R. J., age, 12 years, 6 months.	June 16	12	13.9	.090	
	July 1	14	12.5	.195	Bloody.
	July 8	15	12.2	.070	
	July 9	15	13.3	.060	
	July 18	16	12.0	.065	
	July 21	16	11.0	.145	Bloody.
	July 28	18	12.5	.100	Bloody.
	Aug. 3	19	12.0	.055	
No. 19. G. H., age, 11 years,	June 20	35	12.5	.115	
	June 24	35	9.5	.340	Very swollen udder, slime bloody.
	June 25	35	10.7	.187	Swelling nearly gone, bloody.
	July 10	37	9.5	.030	
	July 22	39	8.7	.060	
	July 29	40	6.3	.215	Swollen udder, slime pussy and bloody.
	July 30	40	5.3	.105	Swollen udder.
	Aug. 10	41	7.0	.065	Bloody.
No. 21. G. H., age, 2 years, 8 months.	June 9	20	8.0	.095	
	June 16	21	7.4	.040	
	June 23	22	7.4	.020	

Cow.	Date.	Weeks in Lactation.	Milk (Pounds).	Slime (Per Cent.).	Remarks.
No. 21 — *Continued.*	July 6	24	7.4	.925	
	July 20	26	6.8	.015	
	July 23	26	6.8	.060	
	July 31	27	7.3	.045	
No. 22. G. H., age, 14 years,	June 18	–	11.0	.295	First milking.
	June 19	–	14.8	.292	
	June 20	–	14.0	.180	
	July 3	–	16.0	.110	
	July 6	–	17.9	.130	
	July 24	–	17.1	.015	
No. 23. G. J., age, 2 years, 7 months.	June 9	18	11.3	.052	
	June 16	19	10.5	.030	
	June 26	20	10.7	.080	
	July 8	22	9.9	.050	
	July 29	24	9.6	.075	
No. 24. G. J., age, 9 years,	June 11	2	16.5	.115	No trouble.
	June 17	3	15.0	.035	
	June 30	5	14.8	.065	
	July 1	5	13.3	.045	
	July 31	9	13.8	.095	
	Aug. 10	10	13.2	.025	
No. 26. G. A., age, 3 years, 4 months.	June 9	55	9.0	.065	
	June 26	57	8.2	.050	
	July 6	58	7.9	.035	
	July 8	58	7.2	.045	
	July 13	60	6.4	.095	Sore teat.
	July 27	61	7.8	.060	
	July 29	61	8.1	.055	
	Aug. 6	62	6.8	.010	Bloody.
No. 48. R. A., age, 8 years, 4 months.	June 16	14	15.8	.090	No trouble.
	June 24	15	16.0	.062	
	June 30	16	15.7	.075	
	July 3	16	14.0	.090	
	July 10	17	14.9	.150	Swollen udder.
	July 14	17	12.6	.095	Swollen udder.
	July 20	18	14.2	.235	Slime bloody, udder swollen badly.

Cow.	Date.	Weeks in Lactation.	Milk (Pounds).	Slime (Per Cent.).	Remarks.
No. 48 — *Continued.*	July 23	18	13.7	.080	
	July 31	19	13.2	.020	
	Aug. 8	20	13.6	.020	
No. 52. R. J., age, 6 years, 3 months.	June 16	13	11.1	.075	
	June 23	14	10.2	.035	
	June 26	14	11.4	.025	
	July 1	15	10.5	.025	
	July 23	18	10.4	.075	
	Aug. 1	19	10.6	.065	
	Aug. 3	19	11.1	.070	
No. 56. G. J., age, 6 years, 6 months.	June 9	6	15.4	.060	
	June 19	7	11.8	.295	
	June 20	7	12.5	.070	
	June 25	8	12.5	.047	
	July 1	9	12.2	.055	
	July 20	12	11.6	.055	
	July 28	13	10.2	.075	
	Aug. 6	14	11.0	.020	
No. 54. G. J., age, —— .	June 9	30	7.0	.165	Bloody.
	June 18	31	6.0	.095	
	June 26	32	7.0	.055	
	July 1	33	7.1	.050	
	July 20	36	8.5	.025	
	July 27	37	7.9	.045	
	Aug. 1	37	6.2	.030	
	Aug. 10	38	3.2	.110	
No. 59. G. H., age, 13 years,	June 20	30	6.5	.055	
	June 25	30	10.5	.075	
	July 6	32	11.1	.045	
	July 18	33	10.0	.050	
	July 24	34	10.0	.065	Bloody.
	July 30	35	10.3	.035	
	Aug. 8	36	10.7	.085	
No. 60. G. H., age, 12 years,	June 15	32	7.8	.160	Hind quarter sore.
	June 24	33	7.3	.085	Bloody.
	July 1	34	5.8	.095	Pus like.

Cow.	Date.	Weeks in Lactation.	Milk (Pounds).	Slime (Per Cent.).	Remarks.
No. 60 — *Continued.*	July 13	36	5.2	.070	
	July 22	37	3.8	.045	
	July 31	38	5.0	.100	Bloody.
No. 82. G. H., age, 11 years,	July 3	-	11.0	.385	First milking.
	July 4	-	12.2	.260	
	July 21	3	15.8	.030	
	July 28	4	17.1	.060	
	Aug. 8	5	15.1	.085	
No. 63. G. S., age, 10 years,	June 8	23	13.5	.100	
	June 18	24	12.4	.080	
	June 24	25	12.8	.040	Bloody.
	July 10	27	11.7	.065	
No. 64. G. S., age, 10 years,	June 8	40	3.8	.138	
	June 15	41	3.6	.140	
No. 66. G. H., age, 11 years,	June 11	48	9.5	.085	
	June 17	49	8.8	.060	
	July 1	51	11.4	.045	
	July 18	53	8.8	.080	
	July 19	53	9.2	.095	
	July 28	54	8.5	.085	Bloody.
No. 68. G. G., age, 5 years, 1 month.	June 11	32	8.0	.085	Bloody.
	June 23	33	8.7	.070	
	July 7	36	7.2	.060	
	July 22	38	7.0	.040	
	Aug. 1	39	6.5	.055	
No. 69. G. H., age, 4 years, 8 months.	June 17	10	19.4	.140	
	July 1	12	18.2	.032	
	July 7	13	19.2	.105	Bloody.
	July 14	14	17.2	.060	
	July 20	15	18.0	.115	Bloody, swollen quarter.
	July 30	16	16.8	.105	Bloody.
No. 71. G. H., age, —— .	June 8	47	20.8	.050	
	June 12	47	17.4	.070	
	June 18	48	16.0	.065	
	June 23	49	15.3	.070	

Cow.	Date.	Weeks in Lactation.	Milk (Pounds).	Slime (Per Cent.).	Remarks.
No. 71 — *Continued.*	July 9	51	15.0	.015	
	July 13	51	18.8	.060	
	July 21	52	14.8	.080	
	July 29	54	11.9	.065	
	Aug. 6	55	15.1	.020	
No. 72. R. G., age, 6 years, 9 months.	June 11	45	6.0	.070	
	June 17	46	6.0	.140	
	June 26	47	5.0	.026	
	July 7	49	7.7	.075	
No. 75. G. G., age, —— .	June 9	19	13.5	.110	Bloody, sore teat.
	June 10	19	13.5	.100	
	June 15	20	11.0	.060	
	June 25	21	10.0	.060	
	July 3	22	10.0	.065	
	July 22	25	8.4	.055	
	July 28	26	9.4	.070	
	Aug. 10	28	5.6	.025	
No. 76. G. G., age, —— .	June 10	18	13.5	.085	Sore teat.
	June 19	19	13.6	.100	Sore teat.
	June 26	20	10.5	.040	
	July 1	21	10.1	.105	Sore quarter and teat.
	July 7	22	9.5	.050	
	July 20	24	9.0	.090	
	July 28	25	8.8	.085	
	Aug. 3	25	8.5	.090	
No. 77. R. J., age, 4 years, 9 months.	June 12	50	7.8	.035	
	June 16	50	9.3	.065	
	June 25	52	8.0	.035	
	July 3	53	9.5	.050	
	July 21	55	14.8	.055	
	July 28	56	8.1	.045	
No. 78. G. G., age, —— .	June 23	–	14.8	.065	
	July 7	–	12.2	.040	
	July 21	–	12.0	.065	
	July 29	–	11.1	.015	

Cow.	Date.	Weeks in Lactation.	Milk (Pounds).	Slime (Per Cent.).	Remarks.
No. 80. R. A., age, 5 years, 2 months.	June 24	–	9.5	.025	
	July 3	–	8.9	.040	
	July 8	–	8.5	.055	
	July 13	–	6.5	.020	
	July 20	–	7.5	.040	
	July 30	–	8.0	.050	
No. 82. G. G., age, —— .	June 10	–	15.1	.105	Bloody.
	June 17	–	12.2	.065	
	June 23	–	11.0	.115	Sore teat.
	July 3	–	11.0	.075	
	July 9	–	10.0	.060	
	July 21	–	8.5	.085	
	July 29	–	10.1	.070	
	Aug. 3	–	10.0	.080	Bloody.
No. 84. G. A., age, 6 years, 4 months.	June 10	21	8.7	.075	
	June 19	22	6.7	.040	
	June 25	23	5.0	.071	
	July 3	24	6.1	.080	
	July 10	25	6.0	.060	
No. 88. G. H., age, 5 years, 6 months.	June 11	31	8.0	.090	
	June 20	32	7.0	.080	
	June 30	33	6.0	.030	
	July 3	34	5.2	.056	
	July 8	35	4.5	.046	
No. 93. G. H., age, —— .	June 19	5	10.2	.085	
	June 30	6	9.3	.027	
	July 13	8	8.5	.065	
	July 21	9	11.2	.055	
	July 31	11	8.4	.055	
	Aug. 6	12	7.5	.035	
No. 94. G. H., age, 10 years,	June 9	14	19.3	.145	
	June 15	15	16.2	.085	
	June 23	16	16.0	.085	
	July 6	18	13.5	.045	
	July 9	18	13.5	.050	
	July 14	19	15.1	.050	

Cow.	Date.	Weeks in Lactation.	Milk (Pounds).	Slime (Per Cent.).	Remarks.
No. 94—*Continued.*	July 24	20	14.4	.060	
	July 29	21	11.6	.050	
	Aug. 6	22	13.0	.040	Bloody.
No. 97. G. H., age, 10 years,	June 30	–	12.0	.055	
	July 3	–	10.8	.060	
	July 8	–	10.4	.055	
	July 20	–	11.0	.035	
No. 101. R. A., age, 5 years, 6 months.	June 10	31	10.2	.020	
	June 18	32	16.3	.035	
	July 1	34	13.8	.065	
	July 7	35	10.5	.085	
	July 10	36	14.0	.085	
	July 21	37	14.0	.055	
	Aug. 3	38	10.0	.065	
	Aug. 8	39	10.0	.060	
No. 102. G. A., age, 10 years, 2 months.	June 12	2	20.8	.190	Bloody.
	June 26	4	19.2	.280	Bloody.
	July 10	6	18.8	.105	Bloody.
	July 23	8	17.5	.095	Bloody.
	July 31	9	17.5	.100	Bloody.
No. 103. R. A., age, 11 years, 4 months.	July 18	–	14.4	.045	
	July 30	–	14.8	.060	
	Aug. 3	–	14.3	.090	Bloody.
No. 104, R. A., age 11 years, .	June 8	11	8.5	.070	
No. 105. G. J., age, 3 years, 9 months.	June 12	18	6.5	.045	
	June 25	20	7.5	.030	
	July 1	21	7.8	.010	
	July 9	22	7.4	.035	
	July 21	24	6.8	.020	
	July 30	25	7.5	.010	
No. 106. G. H., age, 4 years,	June 19	12	14.8	.035	
	June 30	13	14.4	.080	
	July 21	16	14.2	.020	
	July 29	18	12.6	.020	
	Aug. 3	18	13.4	.055	

Cow.	Date.	Weeks in Lactation.	Milk (Pounds).	Slime (Per Cent.).	Remarks.
No. 107. G. H., age, 3 years, 8 months.	June 15	18	9.2	.095	
	June 30	20	10.7	.040	
	July 3	20	10.5	.060	
	July 9	21	10.0	.015	Bloody.
	July 27	24	10.3	.095	Bloody.
	July 28	24	9.4	.010	
	Aug. 8	25	9.0	.045	
No. 108. R. H., age, 3 years, 10 months.	June 17	27	14.5	.070	
	June 19	27	14.5	.035	
	June 24	28	13.5	.060	Bloody.
	July 1	29	13.5	.055	
	July 7	30	12.0	.105	Bloody, quarter swollen.
	July 14	31	12.3	.015	
	July 18	31	11.0	.055	
	July 27	32	11.0	.055	
	Aug. 1	32	11.5	.045	
	Aug. 6	33	11.2	.055	
No. 110. R. H., age 5 years, 4 months.	June 17	33	12.3	.055	
	June 23	34	10.0	.070	
	July 1	35	10.2	.045	
	July 7	36	10.4	.100	
	July 27	38	11.8	.055	
	July 28	39	8.8	.080	
	Aug. 6	40	8.5	.095	Bloody.
No. 111. G. H., age, —— .	July 23	–	12.0	.100	Bloody.
	Aug. 3	–	9.0	.085	Bloody.
No. 112. G. H., age, 3 years,	July 13	–	8.8	.055	
	July 23	–	10.7	.055	
	July 29	–	10.0	.080	
	Aug. 8	–	10.5	.050	
No. 113. R. J., age, 4 years, 5 months.	June 25	–	5.0	.165	First milking.
	June 26	–	5.0	.095	
	June 30	1	10.3	.125	Bloody.
	July 7	2	10.8	.060	Bloody.
	July 14	3	12.2	.030	
	July 27	5	12.4	.040	

Cow.	Date.	Weeks in Lactation.	Milk (Pounds).	Slime (Per Cent.).	Remarks.
No. 113—*Continued.*	July 29	5	11.3	.065	
	July 30	5	10.8	.125	Bloody.
No. 115. G. H., age, —— .	July 13	–	10.3	.020	
	July 31	–	11.5	.005	
	Aug. 3	–	13.8	.120	Bloody.
No. 116. R. H., age, 5 years,	June 11	100	7.0	.150	
	June 15	100	7.6	.052	
	July 11	103	7.0	.075	
	July 19	104	7.8	.075	
	July 24	106	6.5	.045	
	July 29	107	6.0	.090	
	July 31	107	6.3	.050	
	Aug. 10	108	5.8	.045	
No. 117. G. H., age, 3 years, 11 months.	June 12	33	11.3	.077	
	June 30	35	12.0	.075	Bloody.
	July 20	38	12.8	.055	
	July 31	39	13.6	.040	
	Aug. 6	40	11.7	.060	
No. 118. G. J., age, 5 years, .	June 16	30	10.8	.045	
	June 26	31	10.3	.030	
	July 7	33	9.7	.020	
	July 23	35	7.2	.035	
	July 28	36	8.5	.035	
No. 119. G. H., age, 5 years, 2 months.	June 15	35	9.8	.107	Sore teat.
	June 26	36	9.8	.075	
	July 18	39	7.8	.040	
	July 19	39	7.5	.060	
	Aug. 1	41	6.8	.080	
	Aug. 10	42	6.2	.055	
No. 120. G. G., age, —— .	July 24	–	10.6	.055	Bloody.
	Aug. 1	–	10.1	.090	
	Aug. 8	–	13.1	.070	
No. 125. R. H., age, 7 years, 6 months.	June 11	33	18.5	.127	
	June 16	33	19.0	.235	
	June 17	33	18.5	.205	

Cow.	Date.	Weeks in Lactation.	Milk (Pounds).	Slime (Per Cent.).	Remarks.
No. 125 — *Continued.*	June 18	34	19.0	.155	No trouble found at any time with this cow.
	June 19	34	18.0	.147	
	June 20	34	20.0	.155	
	June 24	35	17.9	.185	
	July 1	36	16.4	.185	
	July 8	37	14.7	.235	
	July 13	37	12.9	.100	
	July 22	39	15.3	.120	
No. 127. G. S., age, —— .	June 12	43	13.5	.110	Bloody.
	June 19	44	13.1	.065	
	June 30	45	12.5	.065	
	July 3	46	12.5	.090	
	July 13	47	12.4	.115	
	July 18	48	12.0	.105	
	July 21	48	12.0	.070	
	July 29	49	12.5	.080	
	Aug. 10	50	12.0	.055	
No. 130. G. H., age, 4 years, 2 months.	June 18	25	14.8	.077	
	June 25	26	13.2	.055	
	July 1	27	12.2	.065	
	July 6	27	10.8	.100	
	July 13	28	11.0	.125	Bloody, udder swollen.
	July 23	29	11.3	.085	
	July 28	30	11.5	.090	
No. 131. G. H., age, —— .	June 26	–	14.5	.115	Bloody, sore teat.
	July 7	–	16.5	.070	
	July 22	–	15.6	.060	
	July 30	–	12.0	.060	
No. 133. G. A., age, 4 years, 3 months.	June 11	15	15.0	.027	
	June 16	15	14.5	.060	
	June 23	17	11.3	.055	
	July 7	18	12.1	.060	
	July 21	20	11.0	.095	Bloody.
	July 29	21	11.5	.046	
	Aug. 6	22	10.8	.030	Bloody.

Cow.	Date.	Weeks in Lactation.	Milk (Pounds).	Slime (Per Cent.).	Remarks.
No. 134. R. A., age, 3 years, 11 months.	June 15	55	6.5	.080	
	June 20	55	6.5	.035	
	June 24	56	5.0	.060	
No. 135. G. H., age, —— .	July 24	–	7.5	.090	
	July 28	–	8.4	.130	Cow sick.
	Aug. 8	–	11.0	.095	Bloody.
No. 136. G. H., age, —— .	July 23	–	9.2	.140	
	Aug. 6	–	14.2	.070	
No. 141. G. A., age, 2 years, 10 months.	June 12	20	9.8	.095	
	June 18	21	9.8	.075	
	June 24	22	9.6	.015	
	July 8	23	8.5	.055	
	July 9	23	8.6	.045	
	July 13	24	7.0	.025	
	July 27	26	7.6	.035	
	July 29	26	8.6	.045	
	Aug. 10	27	8.8	.055	
No. 143. G. H., age, 3 years, 10 months.	June 12	8	9.4	.075	
	June 15	8	8.7	.075	Bloody.
	June 26	10	7.5	.105	
	July 9	12	6.5	.010	
	July 11	12	5.8	.070	
	Aug. 10	12	6.5	.050	
No. 144. R. A., age, 3 years, 6 months.	June 10	35	9.6	.105	Bloody.
	June 17	36	9.7	.020	
	July 6	38	8.8	.020	
	July 8	38	7.6	.045	
	July 13	39	8.5	.080	
	July 29	41	7.6	.035	
	Aug. 10	42	8.1	.055	
No. 147. G. A., age, 3 years, 9 months.	June 20	40	–	.040	
	June 23	40	5.8	.050	
	July 3	42	5.0	.076	Bloody.
	July 8	42	5.0	.085	
	July 22	44	3.8	.105	

Cow.	Date.	Weeks in Lactation.	Milk (Pounds).	Slime (Per Cent.).	Remarks.
No. 147—*Continued.*	July 27	45	2.8	.030	
	July 31	45	4.3	.090	Two milkings.
No. 148. R. A., age, 2 years, 10 months.	June 8	28	10.0	.072	Very bloody, udder bruised.
	June 9	28	10.0	.080	
	June 10	28	10.0	.085	Bloody.
	June 20	29	9.5	.045	
	June 24	30	9.4	.095	Bloody.
	July 3	31	7.5	.070	
	July 23	34	5.9	.045	
	July 31	35	4.9	.075	
	Aug. 3	35	5.3	.035	
No. 149. R. A., age, 2 years, 11 months.	June 19	25	8.2	.052	
	June 23	25	7.6	.050	
	July 6	27	6.9	.055	
	July 14	28	5.6	.055	
	July 20	29	7.2	.025	
	Aug. 1	30	6.1	.050	
	Aug. 6	31	6.5	.015	
	Aug. 8	31	6.5	.030	Blood
No. 150. R. G., age, 3 years, 4 months.	June 18	38	8.0	.080	
	June 25	39	7.3	.070	
	July 6	40	7.0	.055	
	July 18	42	6.0	.030	
	July 22	42	6.2	.060	
	July 28	43	6.0	.060	
No. 152. R. H., age, 2 years, 8 months.	June 9	20	11.5	.080	Bloody.
	June 24	22	9.8	.027	
	July 6	24	8.8	.010	
	July 9	24	9.0	.055	
	July 20	26	9.7	.050	
	July 24	26	9.3	.080	Bloody.
	July 30	27	9.2	.050	
	Aug. 3	27	10.4	.020	
No. 153. G. A., age, 3 years, 4 months.	June 6	28	14.1	.057	
	June 18	29	11.4	.070	
	June 26	30	11.8	.085	

Cow.	Date.	Weeks in Lactation.	Milk (Pounds).	Slime (Per Cent.)	Remarks.
No. 153 — *Continued.*	July 3	31	11.3	.075	
	July 8	32	10.4	.020	
	July 21	34	11.0	.010	
	July 30	35	9.8	.025	
No. 81. R. A., age, 5 years, 1 month.	June 12	58	2.5	.106	
No. 154. R. G., age, 2 years, 9 months.	June 11	15	8.0	.085	Bloody.
	July 6	18	7.8	.040	
	July 9	19	7.6	.040	
	July 23	21	7.0	.045	
	July 30	22	7.0	.055	
	Aug. 3	22	6.0	.070	
No. "B." G. G., age, —— .	June 10	–	8.4	.095	
	June 19	–	10.6	.012	
	July 3	–	9.0	.045	
	July 14	–	9.0	.045	
	July 22	–	9.5	.105	Bloody, swollen udder.
	July 31	–	8.6	.015	
	Aug. 10	–	8.0	.080	Bloody.
No. "B." G. G., age, —— .	June 10	–	9.3	.042	
	June 18	–	11.5	.040	
	June 25	–	11.1	.015	Bloody.
	July 7	–	10.9	.050	
	July 21	–	10.5	.060	
	Aug. 1	–	10.0	.015	
No. 28, ...	Aug. 6	–	19.1	.065	
	Aug. 8	–	17.9	.055	Fresh milking.

From the figures in the preceding table conclusions may be drawn which will more or less summarize the results. It was found difficult to take figures for illustrations which were not influenced by some factor other than that under discussion.

1. Different individuals vary greatly in the amount of slime given, even when apparently perfectly normal conditions exist. The following averages of individuals illustrate this: —

	Per Cent.
No. 125, ...	.168
No. 107, ...	.051
No. 115, ...	.048
No. 64, ...	.139

2. The individuals vary greatly in the amount of slime given at different milkings; in successive tests No. 107 gave .095, .04, .015 and .095 per cent. No. 26 varied even more, from .095 to .01 per cent.

3. A few cows seem to be fairly constant in the amount of slime. Nos. 125 and 118 illustrate this very clearly.

4. The amount of slime is affected by sore teats and diseased or bruised udder. No. "B" averages .056 per cent. for two successive tests, the following test she gave .105 per cent. On inquiry of the milker it was found that the cow's udder was bruised. Nos. 48, 75, 76, 108, also illustrate this.

5. It cannot be said that large amounts of slime indicate sore or diseased udder. No. 125 in eleven tests never gave less than .1 per cent., and no trouble could be found. Nos. 16 and 94 both gave very high tests, but without apparent cause.

6. The presence of blood in the slime cannot be said to indicate a diseased udder in so far as close examination would reveal. Bloody slime is not confined to cows giving high amounts of slime.

7. The period of lactation does have an influence. Cows just freshened give a high per cent. of slime; it is often continued for several weeks. In late lactation the tendency seems to be to give a high per cent., yet this does not always hold good. Many of the tests given in the table show that cows which have been milking for a long period give very small amounts of slime.

8. The relation between amount of milk secreted and slime is in no way clear; it is doubtful if there is any such relation.

The Determinations of this Laboratory.—To Lieutenant Davies' data may be advantageously added further determinations of slime from different breeds and individual cows, together with a few determinations made upon commercial milk from different sources. One of the significant things which comes to light in these determinations, which were made incidental to other work, is the tendency to remain more or less constant over successive days. This does not appear in Lieutenant Davies' work.

TABLE IV. — *Amount of Slime from Different Breeds.*

Certified Milk.

[Five pounds of milk used.]

Cow.	BREED.	Condition.	Slime (Dry Weight in Grams).					
53	Jersey,	Normal,	.2041	.1732	.2693[1]	.2590[1]	.3387[1]	–
77	Jersey,	Normal,	.2588	.2646	.3650	.2435[1]	.2800[1]	.2140[1]
78	Guernsey,	– –	.2882	.3710	.2928	.3266	–	–
72	Guernsey,	Abnormal,	3.8232	1.2086[1]	.5963[1]	.4917[1]	.5055[1]	–
85	Ayrshire,	Normal,	.5984	.4342[1]	.4567[1]	.5058[1]	.4974[1]	–
100	Ayrshire,	Normal,	.6171	.7494[1]	.7207[1]	.9793[1]	.6715[1]	–
30	Holstein,	Normal,	.2492	.2506	.3390	.3111	.3462	–
127	Shorthorn,	Abnormal,	.2020	1.7008	1.1392	1.0180	1.1713[1]	1.3065[1]

[1] Weights made on successive days.

TABLE IV. — *Amount of Slime from Different Breeds* — Concluded.

Commercial Milk.[1]

[Ten pounds of milk used.]

	Slime (Dry Weight in Grams).					
Cole,	1.14080	1.1881	1.2210	1.0141	1.1385	1.1423
Adams,	.80275	.7946	.8231	–	–	–
Farm,	.84500	.8305	.9834	–	–	–

From the above study it will be gathered that the amount of slime from cows of the same breed and different breeds is subject to great variation, but the daily production from a cow or from a herd, when determined on successive days, appears to be quite uniform.

Effect of Temperature upon the Amount of Slime.

The temperature of the milk at the time of clarifying exerts some influence upon the amount, as is illustrated in the accompanying tables. The cause of this is not patent unless it may be due to the coalescence of colloidal particles, thus diminishing the extent of surface of the combined particles and increasing the effect of the centrifugalizing forces.

TABLE V. — *Effect of Temperature on Amount of Slime Removed.*

[Twenty pounds of commercial milk used in each test.]

SAMPLE.	Temperature (Degrees F.).	Slime (Grams, Dry Weight, in Duplicate).
I,	55	1.9812 1.9474
	75	1.9664 1.9353
	100	1.9888 1.9800
II,	55	2.0181 2.1736
	75	2.3984 2.4226
	100	2.6228 2.5358
III,	55	1.1897
	75	1.3322
	95	1.5948
IV,	55	1.2342 1.2679
	75	1.3168 1.3786
	95	1.1244 1.2300
V,	55	.9631
	75	1.0524
	95	1.4778

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[1] "Commercial" and "market" as applied to milk are used interchangeably, meaning the ordinary milk that is sold.

TABLE V. — *Effect of Temperature on Amount of Slime Removed* — Concluded.

SAMPLE.	Temperature (Degrees F.).	Slime (Grams, Dry Weight, in Duplicate).
VI,	55	1.4493
	75	1.7300
	95	1.6632
		1.6493
VII,	45	.4210
		.3735
	75	.4485
		.5093
	90	.6140
		.5840
VIII,	45	1.0643
		1.0433
	75	1.0366
		1.1601
	90	1.3069
		1.3357
IX,	45	.9360
		.9282
	75	1.0009
		.9667
	90	1.0092
		1.0050
X,	45	.9849
		1.0345
	75	1.0545
		1.1404
	90	1.1468
		1.2180

TABLE VI. — *Effect of Higher Temperatures on Amount of Slime Removed (Commercial Milk).*

SAMPLE.	90° F.	110° F.	125° F.	140° F.	Held 90° F. for Three Hours.
I,	.9097	1.1783	1.3367	1.6268	1.1385
II,	1.0545	1.2691	1.3358	1.6804	1.1423

Influence of Time and Acidity upon the Amount of Slime.

That the elements of time and acidity operate with temperature became evident as the work proceeded. It is illustrated in the table below.

TABLE VII. — *Effect of Time and Temperature on Amount of Slime Removed.*

[A single sample of commercial milk was used in this test.]

Time.	Temperature (Degrees F.).	Grams (Moist Weight).
At once,	42	1.1015
24 hours,	42	1.1219
48 hours,	42	1.2715
At once,	68	1.3034
24 hours,	68	1.2732
48 hours,	68	1.0384
72 hours,	68	1.3680
90 hours,	68	1.9330[1]
At once,	90	1.2085
24 hours,	90	1.4677
48 hours,	90	1.6412
72 hours,	90	1.9322

[1] High acidity.

Discussion. — It is readily deducible from the above evidence that the amount of slime differs widely when secured from the milk of the same cow, from milk of different individual cows, and from mixed milks, whether the mixed milks have the same origin or not. It is also manifest from the work of this laboratory that samples from the same milk when clarified under the same conditions yield practically the same amount of slime. It follows, therefore, that the causes for these variations must be found in the condition of the animal, the conditions which surround the manipulation of the milk, and the conditions which are involved in the clarification.

From Lieutenant Davies' investigations it seems clear that with the beginning of the period of lactation there is a great increase of slime. This may be attributable to the colostral milk in which colostral cells are numerous. Evidence also seems to point directly to inflammatory conditions of the udder as a cause of increase; garget and other products of inflammation and germ action within the udder are common, probably much more so than is usually recognized. As high as 20 per cent.[2] has been given as the average appearance of garget in milch cows. This does not seem unreasonable when one reflects on the sensitive nature of the mammary gland, and the injuries to udders so frequently encountered by milkers, giving rise to restricted or general mastitis. Doubtless the variability in cell-content must influence the amount of slime to a considerable extent. This may or may not be associated with inflammatory processes. The so-called fibrin may be a variable quantity. These are matters which we shall treat in greater detail later.

Whether milk is dirty or clean, whether many micro-organisms are present or not, whether it is fresh from the cow or has stood for some time, whether it has been held at a low or high temperature, are all in some way related to the variation in the amount of slime obtained.

Again, the clarifier itself and the manner of manipulation have a decided influence upon the slime produced. Whether the machine is run at high speed or low speed, whether the temperature of the milk is high or low, whether the machine has passed quantities of milk or only a small amount, whether it is one size or another and whether it is one make or another, — all exert a modifying influence on the amount of slime thrown out.

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[2] Ernst, W.: Milk Hygiene, translated by Mohler and Eichorn, p. 85.

If, for instance, the amount removed when it is greater in one case than in another is to the credit and efficiency of the machine, will depend on whether the material so removed is dirt or some normal content, as leucocytes. However, it would seem that in the light of the primary purpose of a clarifier the greater the amount of slime removed the better. This will have to be passed over, however, for it has not been the object of the writers to test the efficiency of clarifiers of different manufacturers, or even the different makes of a single manufacturer. This has been studiously avoided.

Food Value of Slime.

The average amount of slime estimated in terms of the entire milk is less than five one-hundredths of 1 per cent. This weight includes foreign elements, as dirt, hairs and such other materials as are likely to find their way into the milk. Only the normal elements, as the so-called leucocytes, the so-called fibrin, fat and casein, can in any sense be regarded as possessing food value. Inasmuch as the $3\frac{1}{2}$ per cent. of fat and the 3 per cent. of casein existing in slime (see analyses below) represent only $3\frac{1}{2}$ and 3 per cent. of five one-hundredths per cent. of the milk, in other words, .00175 and .0015 per cent. of the milk, the conclusion of analysts, that the food value of slime is negligible, is warranted. There is interest attached, however, to the seeming fact that the protein not only comes from the casein that is thrown out, as suggested by McInerney, but that it takes the form of purin bodies, too, as suggested by North. The fat also appears not only to be the fat of milk but, as Bahlman states, the fat of epithelial cells and other detritus. Evidently the cellular elements furnish a recognizable source of some of the material or substances found in the slime; hence, when taken together with the large number of corpuscular elements eliminated in the slime which will be shown later, they cannot be overlooked in the interpretation of milk clarification. This raises a question at once, which, so far as the authors are aware, has not been answered: Do these cellular elements in any manner contain a constituent or constituents which contribute to nutrition? The work of McCollum and Davis,[1] McCollum, Simmonds and Pitz,[2] Osborne and Mendel,[3] Hopkins and Neville,[4] and others suggests the possibility that in these corpuscular elements there may exist what may be called nutritional activators, or bodies which in very small quantities are essential to body maintenance.

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[1] McCollum, E. V., and Davis, M.: The Nature of Dietary Deficiencies of Rice. Journal of Biol. Chem., 1915, Vol. XXIII., p. 181.

[2] McCollum, E. V., Simmonds, E. V., and Pitz, W.: The Relation of the Unidentified Dietary Factors, the Fat-soluble A and Water-soluble B, of the Diet to the Growth-promoting Properties of Milk. Jour. of Biol. Chem., 1916, Vol. XXVII., No. 1, p. 33.

[3] Osborne, T. B., and Mendel, L. B.: Milk as a Source of Water-soluble Vitamine. Jour. of Biol. Chem., 1918, Vol. XXXIV., No. 3, p. 537.

[4] Hopkins, F. G., and Neville, A.: A Note concerning the Influence of Diets upon Growth. Biochem. Jour., 1913, Vol. VII., p. 97.

Chemical Analyses of Clarifier Slime.

Analysis by Bahlman.[1]

	Per Cent.
Protein (nitrogen x 6.38),	67.9
Fat,	3.4
Milk sugar,	7.8
Crude fiber,	2.2
Silica,	3.8
Oxide of iron,	.5
Oxide of alumina,	.6
Calcium phosphate,	3.6
Potassium phosphate,	6.2
Sodium and potassium chloride,	.1
	96.1
Undetermined,	3.9
	100.0

Analysis by McInerney.[2]

Experiment.	Fat (Per Cent.).	Water (Per Cent.).	Total Solids (Per Cent.).	Ash (Per Cent.).	Nitrogen (Per Cent.).	Casein (Per Cent.).
1,	4.0	70.13	29.87	4.17	.43	2.74
2,	5.0	71.86	28.14	2.73	.23	1.46
3,	3.4	70.04	29.96	3.81	.71	4.52
4,	3.2	69.92	30.08	3.00	.14	.89
5,	4.0	75.50	24.50	2.74	.31	1.97
6,	5.0	71.01	28.99	3.36	.10	.63
7,	3.7	71.35	28.65	2.59	.49	3.12
8,	4.0	70.87	29.13	2.83	.27	1.72
Average,	4.0	71.33	28.67	3.15	.33	2.13

Analysis by North.[3]

	Per Cent.
Total solids,	30
Fat,	3
Ash,	3
Nitrogenous organic compounds,	24

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[1] Bahlman, Clarence: Milk Clarifiers. Am. Jour. Pub. Health, 1916, Vol. VI, No. 8, pp. 855, 856.

[2] McInerney, T. J.: Clarification of Milk, Cornell University Agricultural Experiment Station. Bulletin No. 389, April, 1917, p. 499.

[3] North, Charles E.: The Creamery and Milk Plant Monthly, Vol. II, No. 1, p. 19.

We may conclude for the present, at least, that the slime cast out by the clarifier has no nutritional significance, for in amount it is negligible and in quality value there exist no definite data.

This laboratory has concerned itself with some determinations of fat in slime to ascertain whether breed or amount of slime affected the per cent. of fat present. No relation can be seen by the authors. The following tables will contribute information which makes this conclusion reasonable: —

TABLE VIII. — *Determination of Fat in Slime from Different Breeds.*

Cow.	BREED.	Weight of Slime (Dry).	Per Cent. of Fat.	Weight of Slime (Dry).	Per Cent. of Fat.	Weight of Slime (Dry).	Per Cent. of Fat.	Weight of Slime (Dry).	Per Cent. of Fat.
53	Jersey, . . .	.2041	4.3	-	-	-	-	-	-
77	Jersey, . . .	.2588	6.5	-	-	-	-	-	-
78	Guernsey, . .	.2928	5.0	.3939	4.9	-	-	-	-
72	Guernsey, . .	-	-	-	-	-	-	-	-
85	Ayrshire, . .	.5984	3.9	.4342	3.8	.4567	3.9	.5058	3.8
100	Ayrshire, . .	.7494	3.5	.7207	3.6	.9793	3.6	-	-
30	Holstein, . .	.3390	3.5	-	-	-	-	-	-
127	Shorthorn, . .	1.7008	3.5	1.1713	3.6	1.3065	3.5	-	-

Likewise no relation can be established between total solids of the cow's milk and the slime produced.

TABLE IX. — *Determination of Total Solids in Slime from Different Cows.*

Cow 127.		Cow 72.		Cow 100.		Cow 85.		Cow 53.	
Weight of Slime (Dry).	Per Cent. of Solids.	Weight of Slime (Dry).	Per Cent. of Solids.	Weight of Slime (Dry).	Per Cent. of Solids.	Weight of Slime (Dry).	Per Cent. of Solids.	Weight of Slime (Dry).	Per Cent. of Solids.
1.1713	12.22	.2472	12.75	.7207	12.20	.4567	12.31	.2693	12.55
1.3065	11.97	.2740	12.50	.9793	11.78	.5058	12.42	.2590	12.90
1.1940	11.80	.2245	12.08	.6715	11.60	.4974	12.45	-	-
1.0472	11.51	.2317	12.45	-	-	-	-	-	-
.8930	11.85	.2962	12.49	-	-	-	-	-	-
1.6843	11.86	-	-	-	-	-	-	-	-
1.3548	11.90	-	-	-	-	-	-	-	-

The same holds true when these determinations are followed over several successive days. Possibly the differences are so small that they do not become sufficiently evident against the fluctuations in the amount of slime eliminated.

TABLE X. — *Determination of Total Solids in Slime over Successive Days*

		Thursday.	Friday.	Saturday.	Sunday.	Monday.	Tuesday.
Betty III: —							
Forenoon,	Weight of slime (dry),	–	.1289	.2064	.0941	.1127	.1082
	Per cent. of solids,	–	12.1290	13.2800	12.9900	12.9800	12.7800
Afternoon,	Weight of slime (dry),	.1440	.1043	.1551	.1127	–	–
	Per cent. of solids,	14.6400	13.7300	13.0800	13.6600	–	–
Red IV: —							
Forenoon,	Weight of slime (dry),	.4385	.4607	.4452	.4418	–	.4455
	Per cent. of solids,	–	14.0900	13.9500	13.5700	13.7300	14.0200
Afternoon,	Weight of slime (dry),	–	.4970	.4205	.4113	–	–
	Per cent. of solids,	–	14.4900	–	13.5000	–	–

LEUCOCYTES (SO-CALLED) IN SLIME.

That the clarifier throws out of the milk a large proportion of the so-called leucocytes is the testimony from various sources. The number eliminated, moreover, is usually determined by the examination of milk before and after clarification. It is desirable, therefore, to treat this particular subject more fully in connection with other corpuscular elements under the discussion of milk. Determinations, however, which have been made from slime directly are quite limited because of the great possibility of error and the difficulties involved, but are helpful in arriving at a knowledge of the clarifier situation. Hammer[1] has estimated as many as 830,000,000 to 1,120,000,000 per cubic centimeter of moist slime.

The estimates of this laboratory are based on certified and market milk and upon individual cow's milk. The authors do not deem this method as accurate as the determination of leucocytes in milk before and after clarification. This attempt at determination does indicate forcibly that the cellular elements of milk make up a no mean portion of the total slime eliminated.

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[1] Hammer, B. W.: Agricultural Experiment Station, Iowa State College of Agriculture and Mechanic Arts. Research Bulletin No. 28, January, 1916.

TABLE XI. — *Leucocytes per Gram in Slime from Certified Milk.*

SAMPLE.	Cow.	Number per Gram.	SAMPLE.	Cow.	Number per Gram.
1, ...	33	104,000,000	14, ...	56	90,000,000
2, ...	77	19,500,000	15, ...	77	–
3, ...	33	72,800,000	16, ...	24	20,000,000
4, ...	77	62,400,000	17, ...	33	420,000,000
5, ...	77	20,500,000	18, ...	62	670,000,000
6, ...	146	30,900,000	19, ...	146	200,000,000
7, ...	33	40,000,000	20, ...	77	330,000,000
8, ...	77	32,000,000	21, ...	56	442,000,000
9, ...	33	28,000,000	22, ...	24	390,000,000
10, ...	77	24,500,000	23, ...	62	80,000,000
11, ...	33	70,000,000	24, ...	62 and 33	300,000,000
12, ...	62	–	25, ...	62 and 33	600,000,000
13, ...	146	3,000,000			

NOTE. — The slime was macerated in a definite quantity of physiological solution and the cells determined in the suspension. All cells, however, are not released from the slime by this method.

TABLE XII. — *Leucocytes per Gram in Slime from Commercial Milk.*

SAMPLE.	Number per Gram.	SAMPLE.	Number per Gram.
1, ...	300,000,000	4, ...	350,000,000
2, ...	400,000,000	5, ...	270,000,000
3, ...	200,000,000	6, ...	420,000,000

NOTE. — This slime was treated in the same manner as in the case of certified milk.

Further discussion of this subject will be deferred to the discussion of corpuscular elements of milk, on page 196.

THE FIBRIN (SO-CALLED) IN SLIME.

The constituent of milk which has been designated as fibrin because it responds to the methods of staining fibrin is approximately completely removed, as will be gathered from the tables given later (see page 202).

TABLE XIII. — *Presence of Fibrin in Slimes from Certified Milk.*

Sample.	Cow.	Fibrin.	Sample.	Cow.	Fibrin.
1,	33	+	14,	56	+
2,	77	+	15,	77	+
3,	33	+	16,	24	+
4,	77	+	17,	33	+
5,	77	+	18,	62	+
6,	146	+	19,	146	+
7,	33	+	20,	77	+
8,	77	+	21,	56	+
9,	33	+	22,	24	+
10,	77	+	23,	62	+
11,	33	+	24,	33 and 62	+
12,	62	+	25,	33 and 62	+
13,	146	+			

THE DIRT IN SLIME.

By dirt is meant those extraneous substances which find their way into milk from without, or after the milk has left the udder. All milks, whether certified or ordinary market milk, contain some dirt. It appears, however, in different quantities in different milks, and the amount present in a general way corresponds closely to the grade of the milk.

An analysis of the dirt found in or gaining entrance to milk has resulted in the recognition of definite substances associated with the cow, stable, milker or utensils. Some of the materials are feces, dust, hairs, straw, hay, epithelial cells, — in short any loose material on the cow or easily detached from the cow, the milker, the stall; substances floating in the air as the result of stirring hay or bedding or any dusty articles in the stable; material adherent to the pail; and other foreign matter reaching the milk through flies, straining, etc.

In this particular connection our interests center in what the clarifier may do toward undoing what has been done in milking and handling milk. During the process of milking, as a rule, the dirt is added; then an effort is made to remove it by straining and render it harmless by pasteurization. The clarifier is now added as a means to assist in the removal of dirt.

It is evident that the clarifier as a centrifuge cannot remove that portion of the dirt which goes into solution. No centrifuge can do this as long as the solution diffuses throughout the whole mass; accordingly, this should not be charged against the machine, because it is beyond the reach of any present practical device, mechanical or otherwise.

TABLE XIV. — *Does an Increase in Dirt Mean an Increase in Bacteria in Clarified Milk and Water?*

1. Determine by adding definite quantities of dirt to water, and estimate number of bacteria per cubic centimeter before and after clarification.

	BACTERIA PER CUBIC CENTIMETER.	
	Before.	After.
Sample I, .5000 gram in 1 liter,.	30,000	40,000
Sample II, .5000 gram in 1 liter,	40,000	50,000
Sample III, .2000 gram in 1 liter,	30,000	20,000
Sample IV, .1000 gram in 1 liter,	10,000	10,000

2. Determine by adding similar quantities of dirt to milk, estimating the number of bacteria per cubic centimeter before and after clarification.

Adding .5000 Gram of Dirt to Milk Containing 100,000,000 Bacteria per Cubic Centimeter.

	BACTERIA PER CUBIC CENTIMETER.	
	Before.	After.
Sample I,	160,000,000	75,000,000
Sample II,	225,000,000	175,000,000

Adding .2000 Gram of Dirt to Milk Containing 15,000,000 Bacteria per Cubic Centimeter.

Sample III,	50,000,000	8,000,000

Adding .1000 Gram of Dirt to Milk Containing 22,000,000 Bacteria per Cubic Centimeter.

Sample IV,	40,000,000	30,000,000

A determination of the solubility of dirt was undertaken to set before the reader just the nature of the dirt problem. The first series of determinations was made by placing a combination of dry manure, curryings and dust of definite weight, which might get into milk easily, into water as a menstruum, then the suspension and solution were filtered or clarified. Later, milk was employed as a menstruum in place of water.

TABLE XV. — *Determinations of Solubility of Dirt. Insoluble Dirt Removed by Filtration.*

No. 1.

	Grams.
Weight of dirt added to 500 cubic centimeters of water,	.1049
Weight of dirt recovered,	.0889
Weight of dirt entering solution,	.0160

Per cent. of soluble dirt, 16.

No. 2.

Weight of dirt added to 500 cubic centimeters of water,	.1000
Weight of dirt recovered,	.0798
Weight of dirt entering solution,	.0202

Per cent. of soluble dirt, 20.

No. 3.

Weight of dirt added to 500 cubic centimeters of water,	.2031
Weight of dirt recovered,	.1700
Weight of dirt entering solution,	.3310

Per cent. of soluble dirt, 12.

TABLE XVI. — *Determinations of Solubility of Dirt. Insoluble Dirt Removed by Clarification.*

No. 1.

	Grams.
Dirt added in 1,000 cubic centimeters of water,	.5000
Dirt recovered from clarifier,	.4210
Dirt lost as soluble,	.0786

Per cent. entering solution, 15.

No. 2.

Dirt added in 1,000 cubic centimeters of water,	.5000
Dirt recovered from clarifier,	.4210
Dirt lost as soluble,	.0786

Per cent. entering solution, 16.

Dry manure is evidently more soluble than the dirt used in the preceding tests.

TABLE XVII. — *Determinations of the Solubility of Dry Manure in Water.*

No. 1.

	Grams.
Manure (dry) added to 1,000 cubic centimeters of water,	.2000
Manure recovered,	.1535
Manure entering solution,	.0465

Per cent. of solubility, 23.3.

No. 2.

Manure (dry) added to 1,000 cubic centimeters of water,	.2000
Manure recovered,	.1520
Manure entering solution,	.0480

Per cent. of solubility, 24.

No. 3.

Manure (dry) added to 1,000 cubic centimeters of water,	.2000
Manure recovered,	.1501
Manure entering solution,	.0499

Per cent. of solubility, 24.5.

An attempt to add dirt to certified milk and recover or determine it after passing the clarifier was undertaken by the method of differences. This, however, is subject to the error in clarifying the same sample of milk in two lots; the possibility of such error can be ascertained by consulting page 160. Even though the same conditions are observed throughout as considered previously, except the addition of dirt, the error resulting in clarification is real, and the method of differences here used cannot be accepted as absolute. So difficult is it to extract dirt from slime and weigh it that the results must be considered as indicative only.

If, for instance, an addition of a solvent to the slime for releasing the dirt is made, the solution of the dirt is increased. When 1 per cent. of KOH is added to dry manure the per cent. of solution goes to 28.5, 32.5 and 32, instead of 24 and 24.5, as in the case of water.

To illustrate the results obtained by the addition of about .2000 to .5000 gram of dirt to one liter of milk, the following determinations are given: —

TABLE XVIII. — *Solubility of Dirt in Milk.*

	Grams.
No. 1.[1]	
Slime from 1 liter of normal milk,	2.2504
Slime from 1 liter of normal milk + .5000 gram dirt,	2.9123
Difference representing dirt recovered,	.6619
No. 2.	
Slime from 1 liter of normal milk,	1.1276
Slime from 1 liter of normal milk + .5044 gram dirt,	1.5519
Difference representing dirt recovered,	.4243
No. 3.	
Slime from 1 liter of normal milk,	1.7432
Slime from 1 liter of normal milk + .2000 gram dirt,	1.9340
Difference representing dirt recovered,	.1908

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[1] In this case the difference represents more dirt than was added.

In the above samples the certified milk or normal milk represented the minimum amount of dirt present in milk; accordingly, it doubtless had little effect on the results obtained. While it is unjustifiable to say that the amounts recovered from the slime, after the milk has had added a definite amount of dirt and has been through a clarifier, indicate the efficiency of the clarifier in removal of dirt, it is justifiable to infer that a portion of the insoluble part is removed. A lack of exact methods, as heretofore hinted, by which dirt is separated from the remainder of the slime precludes drawing more definite conclusions or giving more satisfactory data.

The removal of dirt has been approached from another angle, which will help in understanding the nature of dirt in milk in its relation to clarification. In one instance 5 pints of commercial milk were passed through the Wisconsin Sediment Tester, using individual discs of cotton for each pint. The milk was then allowed to pass directly into the clarifier receiving can and clarified immediately. The slime eliminated by the clarification was tested by macerating the slime and centrifuging. Visible amounts of dirt were present in the bottom of the tubes. From this one gathers that the clarifier still removes dirt after the milk has been passed through the cotton disc of the Wisconsin Cotton Disc or Sediment Tester.

In another instance this trial was made with 2 pints of commercial milk. Dirt was recognized after submitting the milk to the same procedures as above. Evidences of dirt appeared on the clarifier bowl also.

A little different form of experimentation was then adopted to demonstrate the efficiency of the clarifier in removing insoluble dirt. Definite quantities of milk were run through the clarifier; a sample of clarified milk was taken from time to time, centrifuged and examined for dirt. Table XIX gives the results of this experiment.

TABLE XIX. — *Efficiency of Clarifier in Eliminating Dirt.*

[All samples of milk showed presence of dirt before clarification. Claimed maximum efficiency of clarifier, 45 pounds.]

LOT.	Pounds of Milk.	Centrifuge Test.
I,	10	No dirt observable.
	20	No dirt observable.
	30	No dirt observable.
	40	No dirt observable.
	50	Slight trace observable.
	60	Slight trace observable.
	70	Slight trace observable.
	80	More dirt observable.
II,	20	No dirt observable.
	40	No dirt observable.
	60	Slight trace observable.
	80	Slight trace observable.
III,	20	No dirt observable.
	40	No dirt observable.
	60	Slight trace observable.
	80	Slight trace observable.
IV,[1]	10	No dirt observable.
	20	Slight trace observable.
	30	Slight trace observable.
	40	More dirt observable.
	50	More dirt observable.
	60	More dirt observable.
	70	Original dirt observable.
	80	Original dirt observable.

[1] Sawdust was present.

It is legitimate to claim that the cotton disc in the Wisconsin Sediment Tester is as good a strainer as is employed, but it is not wholly efficient. The clarifier removes insoluble dirt which has not been removed by the tester. Again, the clarifier removes insoluble dirt to such an extent when running within its prescribed limitations that it is impossible to detect it by any methods used by the investigators. Of course, dirt which has gone into solution is beyond reclamation. It is doubtless true that the clarifier is the most efficient strainer known when the specific gravity of the dirt is not lighter than the milk. It practically removes all insoluble dirt.

Micro-organisms in Slime.

It is possible to study the number of micro-organisms in the slime eliminated from milk as well as the number of micro-organisms before and after clarification. It would be better to use the slime in this determination were it feasible to release the micro-organisms from the slime, since in the determination before and after clarification colonization with its difficulties interferes to such an extent as to vitiate the results.

To demonstrate this difficulty in the release of micro-organisms from slime, and at the same time to indicate the micro-organisms eliminated from milk which do not reveal themselves in the counts before and after clarification, the following tables are introduced. In these efforts it is doubtful whether 50 per cent. have been made available for counting.

TABLE XX. — *Effect of Agitation of Slime Suspensions on Bacterial Liberation.*

Certified Milk.

	SAMPLE I.		SAMPLE II.		SAMPLE III.		SAMPLE IV.	
	Portion A.	Portion B.	Portion A.	Portion B.	Portion A.	Portion B.	Portion A.	Portion B.
Germ content before clarification,	2,000	2,000	5,000	5,000	2,000	2,000	1,000	1,000
Germ content after clarification,	1,200	1,200	4,000	4,000	1,500	1,500	900	900
Weight of slime (grams),	1.192	.876	1.091	.889	.7950	.8170	-	-
Slime macerated in physiological salt solution and made up to original amount of milk: —								
Germ content, when agitated (per cubic centimeter),	3,000	-	2,000	-	1,000	-	400	-
Germ content, when not agitated (per cubic centimeter),	-	800	-	1,100	-	700	-	300

TABLE XX. — *Effect of Agitation of Slime Suspensions on Bacterial Liberation* — Concluded.

Commercial Milk.

	SAMPLE I.		SAMPLE II.		SAMPLE III.		SAMPLE IV.		SAMPLE V.	
	Portion A.	Portion B.	Portion A.	Portion B.	Portion A.	Portion B.	Portion A.	Portion B.	Portion A.	Portion B.
Germ content before clarification,	190,000	190,000	100,000	100,000	2,000,000	2,000,000	100,000	100,000	1,750,000	1,750,000
Germ content after clarification,	200,000	200,000	120,000	120,000	2,100,000	2,100,000	200,000	200,000	2,500,000	2,500,000
Weight of slime (grams),	.685	.632	.986	.764	1.189	1.249	.972	1.183	1.174	1.485
Slime macerated in physiological salt solution and made up to original amount of milk: — Germ content, when agitated (per cubic centimeter),	100,000	-	75,000	-	1,500,000	-	80,000	-	1,250,000	-
Germ content, when not agitated (per cubic centimeter),	-	65,000	-	30,000	-	1,250,000	-	40,000	-	750,000

TABLE XXI. — *Releasing of Micro-organisms from Slime.*

Certified Milk.

[One liter employed for each sample.]

SAMPLE.	Bacteria per Cubic Centimeter in Milk.	BACTERIA PER CUBIC CENTIMETER —		
		In First Suspension.	In Second Suspension.	In Third Suspension.
Before clarification,	10,000	5,000	500	200
After clarification,	10,000	3,000	200	100
Before clarification,	15,000	4,000	1,000	100
After clarification,	10,000	1,000	500	100
Before clarification,	2,500	2,000	1,500	150
After clarification,	2,300	1,700	500	200
Before clarification,	14,000	4,200	2,500	–[1]
After clarification,	12,000	3,000	1,000	–[1]
Before clarification,	4,000	2,000	500	200
After clarification,	6,000	2,000	300	100
Before clarification,	15,000	1,500	1,100	300
After clarification,	18,000	1,000	500	200
Before clarification,	500	800	400	40
After clarification,	600	2,000	300	10

[1] Less than 100.

Commercial Milk.

SAMPLE.	Bacteria per Cubic Centimeter in Milk.	Weight of Slime from Milk.	FIRST SUSPENSION.		SECOND SUSPENSION.	
			Bacteria per Cubic Centimeter.	Weight of Slime.	Bacteria per Cubic Centimeter.	Weight of Slime.
Before clarification,	400,000	.9150	40,000	.0300	16,000	.0200
After clarification,	350,000		17,000		1,000	
Before clarification,	75,000	.9910	20,000	.0340	1,000	.0130
After clarification,	50,000		25,000		6,000	
Before clarification,	320,000	.8940	75,000	.0450	–	–
After clarification,	280,000		40,000			

Table XX points out that, when the slime is built up to the same amount as the original milk from which it has been obtained by means of sterile physiological salt solution, the number of organisms recovered when agitated may be even more than in the original determination in the milk before clarification. It further shows that agitation has a decided effect in releasing the micro-organisms probably from both the slime and colonies, but, on the other hand, it doubtless falls very much short in its purpose.

Table XXI reveals the effect of repeated maceration and agitation upon the releasing of micro-organisms from slime.

Both tables seem to reveal the fact that estimates made from milk before and after clarification have little value.

To bring out the results obtained by other laboratories and by this laboratory in efforts to count organisms in slime, it is pertinent to insert the following tables, but these should be interpreted in the light of the preceding attempts to release the micro-organisms. No other conclusion can be drawn from these figures than the most conspicuous failure to determine the number of micro-organisms in slime, and yet this is the most reliable approach available at the present time. The values secured by repeated macerations and suspensions are far in advance of any other determinations of micro-organisms.

Some of Hammer's findings are as follows: —

TABLE XXII. — *Micro-organisms Found in Slime (Hammer).*

Pounds of Milk Clarified.	Slime (Cubic Centimeter).	Bacteria per Cubic Centimeter of Slime.	Pounds of Milk Clarified.	Slime (Cubic Centimeter).	Bacteria per Cubic Centimeter of Slime.
635	70	38,000,000	953	65	675,000,000
837	125	830,000,000	1,249	125	860,000,000
725	90	31,000,000	1,147	250	435,000,000
1,150	70	1,445,000,000	1,356	125	278,000,000
918	70	710,000,000	1,241	100	680,000,000
1,169	45	790,000,000			

TABLE XXIII. — *An Attempt to Estimate the Number of Bacteria in the Slime Removed from Certified Milk as Produced by Individual Cows.*

SAMPLE.	COW.	Number of Bacteria per Gram of Moist Slime.
1,	33	570,000
2,	77	300,000
3,	33	30,000
4,	77	20,000
5,	77	430,000
6,	146	68,000
7,	33	50,000
8,	77	33,000
9,	33	90,000
10,	77	52,000
11,	33	50,000
12,	62	–
13,	146	45,000
14,	56	540,000
15,	77	–
16,	24	220,000
17,	33	60,000
18,	62	110,000
19,	146	580,000
20,	77	650,000
21,	56	290,000
22,	24	110,000
23,	62	145,000
24,	62 and 33	17,000
25,	62 and 33	550,000
26,	33	360,000
27,	77	200,000
28,	33	152,000
29,	77	300,000
30,	33	100,000
31,	77	150,000
32,	33	100,000
33,	77	500,000
34,	33	200,000
35,	77	100,000
36,	33	570,000
37,	77	300,000

TABLE XXIV. — *An Attempt to Estimate the Number of Bacteria in the Slime Removed in Market Milk.*

SAMPLE.	Number of Bacteria per Gram of Moist Slime.
1,	750,000,000
2,	15,000,000
3,	26,000,000
4,	25,000,000
5,	900,000
6,	60,000,000
7,	50,000,000
8,	6,000,000
9,	35,000,000
10,	1,500,000
11,	4,200,000
12,	4,500,000
13,	3,200,000
14,	2,800,000
15,	4,000,000

The results of counting the micro-organisms in slime are therefore unsatisfactory, yet it is evident that very large numbers are imbedded in it, sufficient at times, so far as the tables are concerned, to overthrow the counts obtained in milk before and after clarification. It is only through the study of the micro-organisms in slime, and the suspension of specific organisms which will be given later, that any adequate notion of what occurs in this respect is obtained.

For purposes of illustrating the operation of the clarifier in the action on micro-organisms, the following table is furnished. Other than this little significance is to be given to results shown.

TABLE XXV. — *Bacteria per Gram of Moist Slime in the Three Seeming Layers.*

		Sample VI.	Sample IX.	Sample XII.
Bottom	Direct,	30,000,000	350,000,000	50,000,000
	Plate,	1,500,000	200,000,000	24,000,000
Middle	Direct,	30,000,000	450,000,000	45,000,000
	Plate,	1,100,000	200,000,000	12,000,000
Top	Direct,	30,000,000	600,000,000	42,000,000
	Plate,	7,000,000	160,000,000	118,000,000

III. MILK.

When milk is subjected to clarification slime is removed. What composes slime and what its significance is has been considered in the foregoing discussion. Apparently the nutritional value of milk has not been materially altered so far as can be determined at present; corpuscular elements have been removed, suspended dirt has been eliminated, micro-organisms have been thrown out in large numbers. These, however, have been determined through the slime. It now remains to study the modifications of milk itself, including, as it does under natural circumstances, all of these elements.

CORPUSCULAR ELEMENTS OF MILK.

The so-called leucocytes are very greatly reduced in numbers by clarification. This will be established by attached data. Whether this removal has any particular meaning *per se* other than demonstrating the efficiency of the clarifier under normal or abnormal conditions cannot be stated positively in the light of our present knowledge. However, the large numbers present in inflammatory processes of the udder have a significance from the standpoint of toxic products and pathogenic micro-organisms, and accordingly may be considered objectionable. The thought, too, of enormous numbers existing in milk due to inflammation, whether local or general, is reprehensible in the same way that visible dirt affects the value. Nevertheless, in normal milk large numbers are found, but whether they possess any inherent qualities as food value or other significance cannot at the present time be satisfactorily interpreted.

The removal of leucocytes or other corpuscular elements, as colostral cells, from milk bears directly upon the interpretation of the efficiency of clarification, in that such products as garget, etc., are removed, and, further, a measure is established.

The determinations made by the Biochemical Laboratory of Boston, quoted by Parker,[1] by Hammer,[2] and by this laboratory, are therefore appended to illustrate the above views.

TABLE XXVI.—*Effect of Clarifying Milk on Cell Counts (Boston Biochemical Laboratory).*

Machine A working at 6,000 Revolutions per Minute.

DATE.	Minutes Elapsed after Starting the Run.	Temperature of Milk at Sampling (Degrees F.).	Average Number of Cells per Field in Unclarified Milk.	Average Number of Cells per Field in Clarified Milk.
May 14, 1915, ...	5	80	17.0	9.0
	25	80	12.0	8.0
	35	85	17.0	4.0
	45	72	17.0	4.0
	47	74	–	13.0
May 18, 1915, ...	20	80	4.0	2.2
	50	82	4.3	2.3
	65	78	13.0	3.4
	75	78	8.0	2.4
	85	83	6.3	1.2
	120	75	3.2	2.3
May 19, 1915, ...	20	76	13.6	6.0
	50	74	6.8	5.4
	60	106	8.0	4.0
	115	96	7.0	5.0
May 20, 1915, ...	20	98	7.0	4.0
	50	74	6.7	4.3
	80	80	27.6	10.5
	90	88	20.2	12.6
	100	78	18.2	12.0
	110	72	19.0	5.0
	115	78	17.0	1.0

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[1] Parker, H. N.: The City Milk Supply, 1917, pp. 257, 258.

[2] Hammer, B. W.: Agricultural Experiment Station, Iowa State College of Agriculture and Mechanical Arts. Research Bulletin No. 28.

TABLE XXVI. — *Effect of Clarifying Milk on Cell Counts* — Concluded.

Machine B working at 5,400 Revolutions per Minute.

DATE.	Minutes Elapsed after Starting the Run.	Temperature of Milk at Sampling (Degrees F.).	Average Number of Cells per Field in Unclarified Milk.	Average Number of Cells per Field in Clarified Milk.
May 14, 1915, ...	5	78	11.0	3.0
	25	79	82.0	2.0
	35	85	9.0	5.0
	45	84	9.0	1.0
May 17, 1915, ...	20	94	8.0	6.0
	60	88	11.0	9.0
	75	92	17.0	5.0
	80	88	4.0	4.0
	85	88	4.0	2.0
	90	90	24.0	4.0
May 19, 1915, ...	20	92	5.7	1.1
	50	88	7.2	3.0
	60	90	6.8	3.0
	65	94	5.6	2.2
May 21, 1915, ...	20	86	14.5	14.0
	50	74	14.0	13.0
	70	78	13.0	11.0
	85	80	14.7	11.8
	95	80	19.0	17.0
	105	72	22.0	19.0

TABLE XXVII. — *Cells per Cubic Centimeter before and after Clarification (Hammer).*

TEMPERATURE OF MILK.	Number of Cells per Cubic Centimeter before Clarification.	Number of Cells per Cubic Centimeter after Clarification.	Per Cent. of Cells thrown out.
58,	266,000	206,000	23
–,	120,000	52,000	57
–,	441,000	290,000	34
–,	572,000	259,000	55
56,	407,000	227,000	44
68,	390,000	247,000	37
55,	171,000	93,000	46
46,	258,000	116,000	55
43,	276,000	220,000	20
41,	376,000	193,000	49
51,	177,000	95,000	46
44,	293,000	265,000	10
54,	448,000	140,000	69
54,	303,000	197,000	35
50,	426,000	274,000	36
61,	276,000	202,000	27
43,	156,000	93,000	40
60,	208,000	159,000	24
46,	832,000	226,000	73
48,	198,000	90,000	55
48,	484,000	378,000	22
48,	610,000	489,000	20
68,	282,000	152,000	46
67,	405,000	145,000	64
64,	216,000	186,000	14
60,	442,000	244,000	45
54,	209,000	158,000	24
60,	301,000	203,000	33
66,	281,000	216,000	23
59,	367,000	302,000	18
52,	182,000	169,000	7
59,	209,000	110,000	47
73,	184,000	102,000	45
70,	230,000	135,000	41

TABLE XXVII. — *Cells per Cubic Centimeter before and after Clarification (Hammer)* — Concluded.

TEMPERATURE OF MILK.	Number of Cells per Cubic Centimeter before Clarification.	Number of Cells per Cubic Centimeter after Clarification.	Per Cent. of Cells thrown out.
70,	159,000	73,000	54
69,	324,000	173,000	47
62,	205,000	95,000	54
62,	308,000	157,000	49
68,	258,000	129,000	50
67,	218,000	112,000	49
65,	287,000	206,000	28
64,	267,000	184,000	31
68,	146,000	61,000	58
81,	196,000	131,000	33
81,	216,000	89,000	59
77,	288,000	149,000	48
71,	253,000	132,000	48
72,	220,000	140,000	36
61,	194,000	140,000	28
61,	120,000	95,000	21
64,	393,000	212,000	46
64,	421,000	316,000	25
Average,	297,481	177,442	39

TABLE XXVIII. — *Leucocytes per Cubic Centimeter in Certified Milk before and after Clarification.*

SAMPLE NO.	Cow.	Before.	After.	Per Cent. Reduction.
1,	33	455,000	65,000	85
2,	77	26,000	11,000	58
3,	33	494,000	56,000	88
4,	77	440,000	234,000	46
5,	77	208,000	30,000	85
6,	146	117,000	13,000	88
7,	33	182,000	19,000	89
8,	77	141,000	11,000	92
9,	33	174,000	23,000	86

TABLE XXVIII. — *Leucocytes per Cubic Centimeter in Certified Milk before and after Clarification* — Concluded.

SAMPLE NO.	Cow.	Before.	After.	Per Cent. Reduction.
10,	77	163,000	21,000	87
11,	33	260,000	21,000	92
12,	62	150,000	13,000	91
13,	146	81,000	17,000	79
14,	56	340,000	35,000	89
15,	77	31,000	13,000	58
16,	24	97,000	17,000	82
17,	33	520,000	190,000	63
18,	62	80,000	26,000	68
19,	146	55,000	13,000	76
20,	77	21,000	7,000	67
21,	56	364,000	39,000	89
22,	24	260,000	26,000	90
23,	62	200,000	25,000	87
24,	62 and 33	370,000	52,000	86
25,	62 and 33	200,000	20,000	90

TABLE XXIX. — *Leucocytes per Cubic Centimeter in Commercial Milk before and after Clarification.*

SAMPLE NO.	Before.	After.	Per Cent. Reduction.
1,	250,000	65,000	74
2,	230,000	30,000	87
3,	130,000	12,000	90
4,	200,000	20,000	90
5,	290,000	50,000	82
6,	400,000	30,000	92

The tables furnish an understanding of the leucocytic situation in clarification. If nothing else is to be attributed to the ejection of cellular elements, it can be safely said that the clarifier does perform its function very satisfactorily in removing normal corpuscular elements, and, further, should there be accumulations or aggregations due to inflammatory conditions, it doubtless eliminates every particle of this heavier suspended mass, inasmuch as the surface is reduced and its power to remain suspended long in the milk destroyed. What is gained by this act is to be estimated by the general understanding that, so far as possible, all traces of inflammatory products should be removed from milk. This is to be done whether any tangible reason can be given or not at present; it is the consensus of opinion that at times, at least, these products are dangerous, especially the micro-organisms giving rise to them.

THE FIBRIN (SO-CALLED) IN MILK.

A substance which has been designated as fibrin is visible in milk when treated with a fibrin staining process. This is almost invariably removed by clarification. It cannot be our purpose to assign to this particular substance any rôle other than existence, in accordance with results of staining. That such results are obtainable can be best verified by actual trial.

TABLE XXX. — *Presence of Fibrin in Certified Milk before and after Clarification.*

SAMPLE NO.	Cow.	Before.	After.
1,	33	+	—
2,	77	—	—
3,	33	+	—
4,	77	+	—
5,	77	—	—
6,	146	+	—
7,	33	+	—
8,	77	+	—
9,	33	+	—
10,	77	+	—
11,	33	+	—
12,	62	+	—
13,	146	+	—
14,	56	+	—
15,	77	+	—
16,	24	+	—
17,	33	+	+
18,	62	+	—
19,	146	+	—
20,	77	—	—
21,	56	+	—
22,	24	+	—
23,	62	+	—
24,	33 and 62	—	—
25,	33 and 62	—	—

TABLE XXXI. — *Presence of Fibrin in Commercial Milk before and after Clarification.*

SAMPLE NO.	Before.	After.	SAMPLE NO.	Before.	After.
1,	+	—	4,	—	—
2,	+	+	5,	—	—
3,	—	—	6,	+	—

MICRO-ORGANISMS IN MILK.

This particular aspect of the work seems to be the most popular for testing the efficiency of the clarifier, and yet it has a faulty basis which is not always considered in conclusions. Microbial counts may tell a very misleading falsehood unless the full story is told and the conditions are fully understood.

Several contributions have been made upon the removal or non-removal of bacteria by the clarifier. Dr. J. Arthur McClintock[1] divided clarifiers into three types, — A, B and C.

Out of 26 tests made with type A, he obtained a reduction of 29.7 to 55.1 per cent.

Out of 22 tests made with type B, he obtained a reduction of —3.5 to 29.8 per cent. Only two instances of increase occurred among the 22 tests. These account for the —3.5 per cent.

Out of 12 tests made with type C, he obtained a reduction of —631 to 35.9 per cent. Only in one instance among these 12 tests did he have an increase, which alone accounts for the —631 per cent.

These results are so different from those which follow that the reviewer hesitates to accept them without further data, and does not feel at liberty to accord with the deductions from his study of the different types of clarifiers. There must be influences at work which the writer failed to record.

There may be gleaned an astounding statement from A. J. Hinkelmann,[2] in which he says: "I have found that the pathogenic bacteria commonly met with are precipitated much more readily than are the non-pathogenic." Such selective power on the part of the clarifier almost bespeaks superhuman capacity. It also indicates that if an organism is pathogenic (which, of course, has only restricted application, depending upon species of animal affected and other conditions) it possesses a distinctive specific gravity. This scarcely seems credible, although it can be understood that some organisms are heavier than others. The division, however, can scarcely be made from pathogenesis alone, if present knowledge has any weight. More may be said concerning this later, in connection with some evidence which the authors may wish to furnish.

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[1] McClintock, J. Arthur: An Investigation of Clarification of Milk. The Milk Trade Journal, 1916, Vol. IV, No. 6, p. 10.

[2] Hinkelmann, A. J.: Micro-organic Weight. Reprint from the Illinois Medical Journal, issue of March, 1916.

A table furnished by W. A. Stocking[1] illustrates results commonly obtained with commercial milk.

TABLE XXXII. — *Effect of a Centrifugal Clarifier upon the Germ-content of Milk (Stocking).*

SAMPLE NO.	Bacteria before Clarifying.	Bacteria after Clarifying.	Numerical Increase.	Per Cent. Increase.
1,	6,000	9,000	3,000	50
2,	15,000	22,000	7,000	46
3,	60,000	156,000	96,000	160
4,	133,000	197,000	64,000	48
5,	370,000	643,000	273,000	73

The seemingly universal increase given by Stocking is not borne out by other workers who furnish extended studies. The explanation for this may be found in the character of the milk used.

Parker quotes the findings of the Biochemical Laboratory of Boston.[2]

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[1] Marshall, C. E.: Microbiology, 1917, p. 390.

[2] Parker, H. N.: The City Milk Supply, pp. 257, 258.

TABLE XXXIII. — *Effect of Clarifying Milk on the Bacterial Count (Biochemical Laboratory).*

Machine A, working at 6,000 Revolutions per Minute.

DATE.	Bacteria per Cubic Centimeter in Unclarified Milk.	Bacteria per Cubic Centimeter in Clarified Milk.	Numerical Increase.[1]	Per Cent. Increase.[1]
May 14,1915, ...	1,700,000	1,900,000	200,000	12
	1,250,000	920,000	—330,000	—26
	950,000	1,500,000	550,000	58
	780,000	1,200,000	420,000	54
	–	1,330,000	–	–
Average, ...	1,170,000	1,370,000	200,000	17
May 18, 1915, ...	360,000	360,000	0	0
	710,000	880,000	170,000	24
	950,000	960,000	10,000	1
	800,000	980,000	180,000	23
	750,000	850,000	100,000	13
	900,000	1,080,000	180,000	20
Average, ...	745,000[2]	851,666[2]	76,666	10
May 19, 1915, ...	1,350,000	1,220,000	—130,000	—9
	1,600,000	1,300,000	—300,000	—19
	850,000	420,000	—430,000	—50
	950,000	500,000	—450,000	—47
Average, ...	1,187,500[2]	860,000	—327,500	—27
May 20, 1915, ...	410,000	270,000	—140,000	—34
	230,000	190,000	—40,000	—17
	600,000	580,000	—20,000	—3
	860,000	1,000,000	140,000	16
	660,000	500,000	—160,000	—24
	650,000	700,000	50,000	7
	750,000	610,000	—140,000	—18
Average, ...	594,285	550,000	—44,285	—7

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[1] This column added by the authors.

[2] Corrected from table.

Table XXXIV. — *Effect of Clarifying Milk on the Bacterial Count (Biochemical Laboratory).*

Machine B, working at 5,400 Revolutions per Minute.

Date.	Bacteria per Cubic Centimeter in Unclarified Milk.	Bacteria per Cubic Centimeter in Clarified Milk.	Numerical Increase.[1]	Per Cent. Increase.[1]
May 14, 1915,	1,100,000	650,000	—450,000	—40
	1,030,000	820,000	—210,000	—20
	600,000	1,010,000	410,000	68
	450,000	900,000	450,000	100
Average,	795,000[2]	845,000	50,000	6
May 17, 1915,	1,070,000	580,000	—490,000	—45
	780,000	980,000	200,000	25
	800,000	950,000	150,000	19
	1,150,000	780,000	—370,000	—32
	850,000	750,000	—100,000	—12
	900,000	1,400,000	500,000	55
Average,	925,000	906,666	—18,334	—2
May 19, 1915,	900,000	800,000	—100,000	—11
	1,110,000	910,000	—200,000	—18
	780,000	660,000	—120,000	—15
	870,000	930,000	60,000	7
Average,	915,000	825,000	—90,000	—10
May 21, 1915,	200,000	180,000	—20,000	—10
	90,000	130,000	40,000	44
	280,000	240,000	—40,000	—14
	130,000	170,000	40,000	30
	550,000	750,000	200,000	36
	760,000	820,000	60,000	8
Average,	335,000	381,666	46,666	14

[1] This column added by the authors.

[2] Corrected from table.

In this table it will be noted that there are cases of increase and cases of decrease in the number of bacteria. In this particular this work is at variance with the conclusions drawn from Stocking's table.

Clarence Bahlman[1] made eight tests of market milk in which he finds an average increase of 27 per cent.

TABLE XXXV. — *Effect of Clarifying Milk on the Microbial Count (Bahlman).*

TEST NO.	BACTERIA PER CUBIC CENTIMETER.		Per Cent. Increase in Bacteria.
	Raw.	Clarified.	
1,	630,000	750,000	19
2,	900,000	980,000	9
3,	1,400,000	1,800,000	28
4,	455,000	730,000	60
5,	418,000	580,000	30
6,	3,150,000	4,005,000	27
7,	2,160,000	2,800,000	30
8,	1,380,000	1,720,000	25
Average,	1,312,000	1,670,000	27

These results correspond closely with those contributed by Stocking. All tests have shown an increase in numbers.

From Hammer[2] are gathered some modifications which give the numerical increase and decrease of micro-organisms in milks containing germ-contents within certain limitations.

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[1] Bahlman, Clarence: Milk Clarifiers. Amer. Jour. of Pub. Health, 1916, Vol. VI, No. 8.

[2] Hammer, B. W.: Studies on the Clarification of Milk. Iowa Agr. Exp. Sta., 1916. Bulletin No. 28.

TABLE XXXVI. — *Bacteria per Cubic Centimeter before and after Clarification (Hammer).*

[Original count under 100,000 per cubic centimeter.]

Bacteria per Cubic Centimeter before Clarification.	Bacteria per Cubic Centimeter after Clarification.	Per Cent. Change in Number.	Bacteria per Cubic Centimeter before Clarification.	Bacteria per Cubic Centimeter after Clarification.	Per Cent. Change in Number.
61,500	58,500	—5	12,700	13,450	6
70,000	61,000	—13	25,800	26,300	2
48,000	71,500	49	22,200	23,800	7
19,550	20,400	4	24,850	20,250	—19
41,000	41,000	0	8,200	7,950	—3
11,650	15,850	36	6,700	6,700	0
83,000	98,500	19	63,000	78,000	24
20,250	15,400	—24	30,500	46,500	52
35,500	31,500	—11	97,000	78,000	—20
91,500	95,500	4	45,500	51,000	12
67,500	70,500	4	22,500	26,700	19
38,000	35,000	—8	16,250	17,300	6
61,000	62,000	2	19,150	20,000	4
56,500	46,500	—18	7,150	9,250	29
35,500	126,500	256	8,300	7,000	—16
24,500	24,500	0[1]	75,500	111,000	47
24,500	24,500	0	73,500	149,500	103
18,500	53,000	186	15,000	28,500	90
48,500	43,000	—11	37,500	35,000	—7
32,500	36,000	11	48,500	63,500	31
19,050	20,150	6	71,500	147,500	106
42,000	41,000	—2	36,500	50,000	37
7,900	6,500	—18	26,000	53,500	106
5,700	6,150	8	97,500	132,000	35
18,450	24,400	32	59,000	63,000	7
9,900	11,100	12			

[1] Corrected from table.

TABLE XXXVII. — *Bacteria per Cubic Centimeter before and after Clarification (Hammer).*

[Original count from 100,000 to 500,000 per cubic centimeter.]

Bacteria per Cubic Centimeter before Clarification.	Bacteria per Cubic Centimeter after Clarification.	Per Cent. Change in Number.	Bacteria per Cubic Centimeter before Clarification.	Bacteria per Cubic Centimeter after Clarification.	Per Cent. Change in Number.
257,000	247,000	—4	450,000	345,000	—23
227,000	219,000	—4	460,000	435,000	—5
179,500	150,500	—16	190,000	392,000	106
226,000	233,500	3	365,000	450,000	23
142,500	139,000	—2	105,000	141,000	34
107,000	117,000	9	141,500	177,000	25
128,000	121,000	—5	142,500	194,000	36
111,000	101,000	—9	460,000	605,000	32
101,000	64,500	—36	430,000	1,235,000	187
131,000	149,500	14	340,000	495,000	46
400,000	450,000	12	390,000	540,000	38
480,000	560,000	17	260,000	400,000	54
233,000	320,000	37	179,000	238,000	33
260,000	435,000	67			

TABLE XXXVIII. — *Bacteria per Cubic Centimeter before and after Clarification (Hammer).*

[Original count over 500,000 per cubic centimeter.]

Bacteria per Cubic Centimeter before Clarification.	Bacteria per Cubic Centimeter after Clarification.	Per Cent. Change in Number.	Bacteria per Cubic Centimeter before Clarification.	Bacteria per Cubic Centimeter after Clarification.	Per Cent. Change in Number.
1,185,000	1,470,000	24	970,000	705,000	—27
5,450,000	5,700,000	5	580,000	655,000	13
1,885,000	1,800,000	—5	645,000	385,000	—40
1,050,000	1,095,000	4	2,385,000	2,985,000	25
2,110,000	2,265,000	7	765,000	1,275,000	67
960,000	1,080,000	12	1,590,000	1,870,000	18
550,000	1,110,000	102	545,000	785,000	44

Fifty-one comparisons were made on samples showing less than 100,000 organisms per cubic centimeter. In 3 cases (6 per cent.) the bacterial content before and after clarification was the same; in 14 cases (27 per cent.) there was a decrease during clarification varying from 2 to 24 per cent., and averaging

12 per cent.; while in the remaining 34 cases (67 per cent.) there was an increase during clarification varying from 2 to 256 per cent. and averaging 41 per cent. If the total 51 samples are considered there was an average increase of 24 per cent.

Twenty-seven comparisons were made on samples containing from 100,000 to 500,000 bacteria per cubic centimeter in the unclarified milk; 9 comparisons (33 per cent.) showed a decrease during clarification varying from 2 to 36 per cent. and averaging 12 per cent., while 18 comparisons (67 per cent.) showed increases varying from 3 to 187 per cent. and averaging 43 per cent. Considering all of the samples there was an average increase of 25 per cent.

Fourteen comparisons were made on samples containing more than 500,000 bacteria per cubic centimeter in the unclarified milk; only 3 comparisons (21 per cent.) showed a decrease during clarification, 1 of 5, 1 of 27, and 1 of 40 per cent. (averaging 24 per cent.), while 11 comparisons (79 per cent.) showed increases varying from 4 to 102 per cent. and averaging 29 per cent. There was an average increase of 18 per cent. when the total 14 samples are considered.

The number of samples of milk under 100,000 bacteria per cubic centimeter does not show a larger percentage of decreased counts than the samples between 100,000 and 500,000 bacteria per cubic centimeter; in fact, the milk samples of over 500,000 bacteria showed a less increase than the samples with a lower number of organisms. All the samples were market milk samples; accordingly, the histories of the samples are unknown. This makes it difficult to draw any specific conclusions. Hammer's work is, however, very interesting in connection with the results of this laboratory, which will be furnished later.

A general critical review of the clarifier tests has been written by Prof. E. G. Hastings for the Journal of the American Medical Association for March 24, 1917. His conclusion intimates that the clarifier may not be a progressive step in the purification of milk. This is a somewhat hasty conclusion without his having investigated the results of its action a little more closely. Too much is superficially apparent in its action to turn it aside with the wave of the hand and the cynical remark, "What next?" An extended acquaintance with the machine and its operations will at least suggest very subtle problems, perhaps much more illuminating if solved than any which have been attacked thus far, and causes one to speculate about milk questions which have been heretofore untouched or remotely surveyed. From time to time these suggestions will be hinted at in the text.

T. J. McInerney[1] has contributed the following table, which indicates the effect of clarification upon the bacterial count in fresh and old milk: —

TABLE XXXIX. — *Effect of Clarification on the Bacterial Content of Fresh Milk (McInerney).*

EXPERIMENT.	BACTERIA PER CUBIC CENTIMETER —		INCREASE —	
	In Unclarified Milk.	In Clarified Milk.	Per Cubic Centimeter.	Per Cent.
1,	700	1,600	900	128.57
2,	2,300	2,400	100	43.48
3,	641	1,825	1,184	184.71
4,	1,250	2,483	1,233	98.64
5,	563	2,900	2,337	415.10
6,	1,400	1,475	75	5.36
7,	525	1,100	575	109.52
8,	6,000	9,000	3,000	50.00
9,	10,000	30,000	20,000	200.00
10,	1,100	1,400	300	27.27
11,	5,000	10,000	5,000	100.00
12,	4,000	4,000	0	–
13,	4,500	18,000	13,500	300.00
14,	3,600	5,000	1,400	38.39
15,	2,100	2,600	500	23.81
16,	3,650	5,550	1,900	52.05
17,	7,000	20,000	13,000	185.71
18,	5,480	12,125	6,645	121.26
19,	10,000	13,000	3,000	30.00
20,	11,320	13,600	2,280	20.14
21,	4,280	8,000	3,720	86.91
22,	4,600	4,250	—350	–
23,	1,600	4,100	2,500	156.25
24,	15,000	22,000	7,000	46.67
25,	53,000	71,500	18,500	34.90
26,	60,000	156,000	96,000	160.00
27,	5,675	5,775	100	1.76
28,	10,200	11,000	800	7.84
Average,	8,410	15,739	7,329	87.15

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[1] McInerney, T. J.: Clarification of Milk. Cornell University Agr. Exp. Sta., 1917. Bulletin No. 389.

TABLE XL. — *Effect of Clarification on the Bacterial Content of Old and Dirty Milk (McInerney).*

Experiment.	Bacteria per Cubic Centimeter — In Unclarified Milk.	Bacteria per Cubic Centimeter — In Clarified Milk.	Increase — Per Cubic Centimeter.	Increase — Per Cent.
1,	830,000	13,900,000	13,070,000	1,574.70
2,	40,000	110,000	70,000	175.00
3,	494,000	6,400,000	5,906,000	1,195.55
4,	133,500	197,500	64,000	47.94
5,	15,000,000	30,000,000	15,000,000	100.00
6,	37,800,000	40,000,000	2,200,000	5.82
7,	1,500,000	3,200,000	1,700,000	113.33
8,	370,000	643,000	273,000	73.78
9,	600,000	1,300,000	700,000	116.67
10,	55,000	175,000	120,000	218.18
11,	19,000,000	160,000,000	141,000,000	742.10
12,	248,000	425,000	177,000	71.37
13,	558,750	1,863,300	1,304,550	233.48
14,	190,000	237,000	47,000	24.74
15,	83,400,000	91,030,000	7,630,000	9.15
16,	1,590,000	1,831,000	241,000	15.16
17,	4,420,000	5,700,000	1,280,000	28.96
Average,	9,778,191	21,000,694	11,222,503	114.77

James M. Sherman[1] has also furnished his results of the bacterial counts before and after clarification.

TABLE XLI. — *Effect of Clarification on the Bacterial Count of Milk (Sherman).*

Test No.	Machine.	Bacteria per Cubic Centimeter — Before Clarification.	Bacteria per Cubic Centimeter — After Clarification.
1,	A	3,700	6,100
2,	A	3,800	6,300
3,	A	5,500	8,500
4,	A	2,900	6,300
5,	A	4,200	6,200
6,	A	4,100	6,200
7,	A	3,400	7,400
8,	A	3,900	6,100
9,	A	3,400	4,900
10,	A	3,000	4,900
11,	A	3,200	6,800
12,	A	4,300	9,600
13,	B	3,300	5,600
14,	B	5,900	7,300
15,	B	9,300	13,800
16,	B	4,800	7,600
17,	B	1,800	3,100
18,	B	2,500	3,300
19,	B	2,900	3,700
20,	B	11,400	13,400
21,	B	4,300	6,400
22,	B	3,600	4,500
23,	B	10,300	13,400
24,	B	7,800	9,300
Average,	–	4,720	7,120

Again there is the decided increase of micro-organisms following clarification.

Although realizing that the usual interpretation of microbial counts in this connection has no basis in actual truth, and there can be no increase because the milk passes through the clarifier so quickly that there is no time for multiplication, and, further, in the slime large masses of organisms are found, this laboratory has felt it desirable, nevertheless, to undertake the determination of the number of organisms in milk before and after clarification, not so much for the purpose of contributing to what has already been given, but rather for the purpose of knowing what is really involved in the determination and what interpretation of the results obtained may be given. Since the operation of clarifying is so short, it is difficult to believe that any multiplication takes place, as has already been stated above. If none takes place then it must be a disruption in colonies, which leads the student to wonder whether there is greater efficiency in micro-organisms liberated from a disrupted colony as compared with the same organisms imbedded in the colony. This will appear later.

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[1] Sherman, James M.: Bacteriological Tests of Milk Clarifier. Jour. of Dairy Science, 1917, Vol. I, No. 3, p. 272.

The authors' studies were carried out under the following conditions: —

The clarifier used was No. 98 De Laval. It was run by a $\frac{1}{6}$-horsepower motor at uniform speed of 7,200 to 7,300 revolutions per minute. The temperature was maintained at 60° C. when clarifying. As soon as the machine reached full speed the milk was passed through. The bowls, discs, etc., were sterilized in an autoclave at 15 pounds pressure for thirty minutes. The milk both before and after clarification was thoroughly mixed prior to taking the samples, which were placed in sterile flasks.

In the case of certified milk, the milk was obtained from the milker in the "certified" stable; in the case of the commercial milk, from the receiving room of the college dairy. The commercial milk came from the farmers in the vicinity of the college, and was not above the average commercial milk. It doubtless reached the clarifier sooner than it would had it been sent to a city from Amherst, then clarified after reaching the city.

For estimating the number of bacteria in milk, the Standard Methods of the American Public Health Association were employed. An effort was made to adhere to these methods in all of our work so far as feasible.

A determination of the number of bacteria cast out by the clarifier into the slime has been undertaken both by a direct count, mathematical calculation, and by repeated maceration and clarification. Methods and discussion will be reserved until after some facts have been placed before the reader.

TABLE XLII. — *Bacteria in Certified Milk from Individual Cows before and after Clarification.*

SAMPLE NO.	COW.	Number of Organisms in 1 Cubic Centimeter of Unclarified Milk.	Number of Organisms in 1 Cubic Centimeter of Clarified Milk.	Per Cent. Increase.
1,	33	5,000	2,000	—60
2,	77	1,100	800	—27
3,	33	4,000	3,000	—25
4,	77	2,000	2,000	–
5,	77	1,100	1,000	—9
6,	146	1,700	3,000	76
7,	33	4,000	2,200	—45
8,	77	1,600	5,000	212
9,	33	12,000	6,000	—50
10,	77	9,000	8,000	—11
11,	33	4,000	3,000	—25
12,	62	4,000	1,100	—72
13,	146	1,500	1,200	—20
14,	56	3,800	5,000	31
15,	77	11,000	9,000	—18
16,	24	3,600	1,200	—66
17,	33	100	500	400
18,	62	500	400	—20
19,	146	1,000	1,200	20
20,	77	2,000	800	—60
21,	56	4,000	1,000	—75
22,	24	1,900	1,100	—42
23,	62	2,000	600	—70
24,	62 and 33	100	200	100
25,	62 and 33	5,000	6,000	20
26,	33	1,700	1,000	—41
27,	77	1,500	500	—66
28,	33	1,300	2,000	53
29,	77	1,000	1,000	–
30,	33	3,000	1,500	—50
31,	77	800	1,300	62
32,	33	1,800	600	—66
33,	77	1,500	1,000	—33

TABLE XLII. — *Bacteria in Certified Milk from Individual Cows before and after Clarification* — Concluded.

SAMPLE NO.	Cow.	Number of Organisms in 1 Cubic Centimeter of Unclarified Milk.	Number of Organisms in 1 Cubic Centimeter of Clarified Milk.	Per Cent. Increase.
34,	33	700	1,900	171
35,	77	700	5,000	614
36,	33	5,000	2,000	—60
37,	77	1,100	800	—27

TABLE XLIII.—*Bacteria in Commercial Milk before and after Clarification.*

SAMPLE NO.	Number of Bacteria in 1 Cubic Centimeter of Unclarified Milk.	Number of Bacteria in 1 Cubic Centimeter of Clarified Milk.	Per Cent. Increase.
1,	250,000	900,000	260
2,	100,000	200,000	100
3,	75,000	65,000	—13
4,	20,000	50,000	150
5,	5,000	12,000	14
6,	125,000	70,000	—44
7,	130,000	400,000	207
8,	25,000	48,000	92
9,	20,000	35,000	75
10,	350,000	250,000	—28
11,	30,000	40,000	33
12,	40,000	50,000	25
13,	30,000	20,000	—33
14,	10,000	10,000	-
15,	16,000	33,000	106

The following superficial and provisional conclusions may be drawn from these tables: —

1. In the case of fresh certified milk about 70 per cent. of the tests give an increase in bacterial content in unclarified milk over the same milk clarified. This leaves 30 per cent. showing an increase after clarification.

2. In the case of commercial milk about 85 to 90 per cent. show an

increase in the bacterial content after clarification over the same milk unclarified.

3. The slime sediment reveals a deposit of bacteria which of course must come out of the milk undergoing clarification (see page 190).

There seems to be a tendency, which is not universal because the milk from different cows varies so, for milk at the time of milking (70 per cent. of the cases) to undergo a reduction in the number of bacteria after clarification as revealed by plating, while milk which stands increases in its number of bacteria after clarification in direct proportion to the time that it is permitted to stand before clarification.

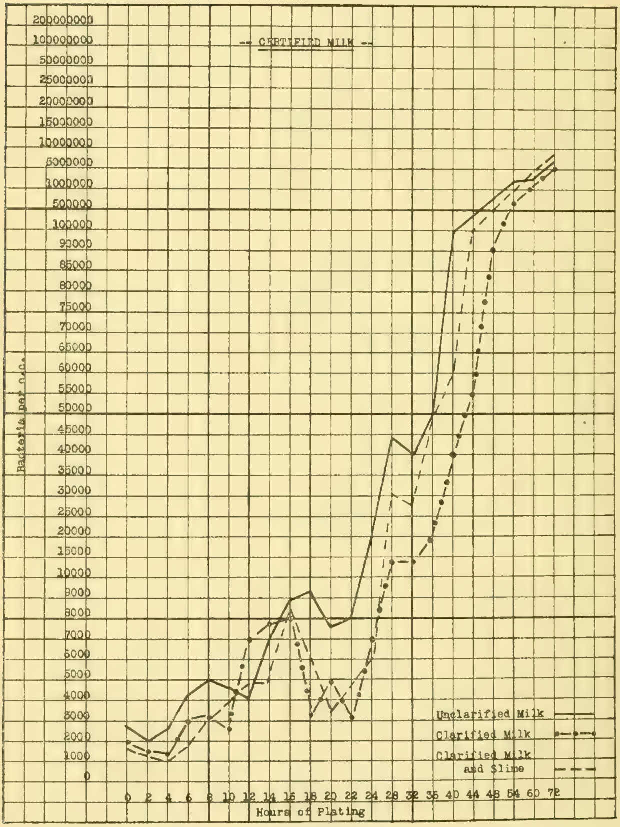
This would indicate that fresh certified milk is freer from colonies and has a greater number of single organisms, and these single bacteria are thrown out with the slime (see "Slime," page 195), in some cases to a considerable extent. In certain instances, however, colonies have formed and are disrupted, thus increasing the bacterial content of certified clarified milk (30 per cent. of the cases).

The commercial milk appears to admit of so much colonizing with the subsequent disruption by the clarifier that a high percentage (85 to 90 per cent.) of samples will give an increased number of bacteria after clarification. Since a large number of bacteria is found in the slime, and there is little opportunity for multiplication during the process of clarification, the increase in the number of bacteria is only apparent and not real.

Thus far we are substantially in accord with the report of the Biochemical Laboratory of Boston, Hammer and Bahlman. Assuming that micro-organisms have no time to multiply, it follows that although a count-increase is evidenced by the plating method, the number is actually reduced by those appearing in the slime.

Serial Counts of Micro-organisms in Clarified and Unclarified Milk over a Period of Time.

Together with the single bacterial counts of milk before and after clarification should be considered two-hour counts of milk, certified and market, unclarified and clarified, extending over seventy-two hours. This study will give a more precise knowledge of the effect of clarification upon the germ-content of milk in spite of the errors creeping in from colonization and plating. It will be seen at once that the graphs depict a situation not revealed by the single count before and after clarification, and they correspond more closely with actual experience. This taken together with other factors, as the character of fermentation resulting from clarification (see page 240), has great significance.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Bacteria per c.c.
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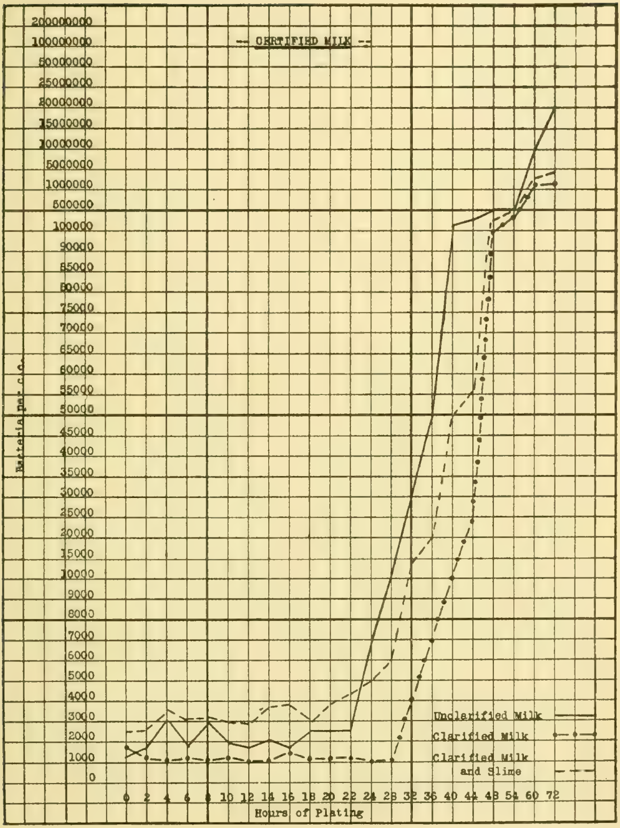
Hours of Plating
Unclarified Milk
Clarified Milk
Clarified Milk and Slime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Bacteria per c.c.
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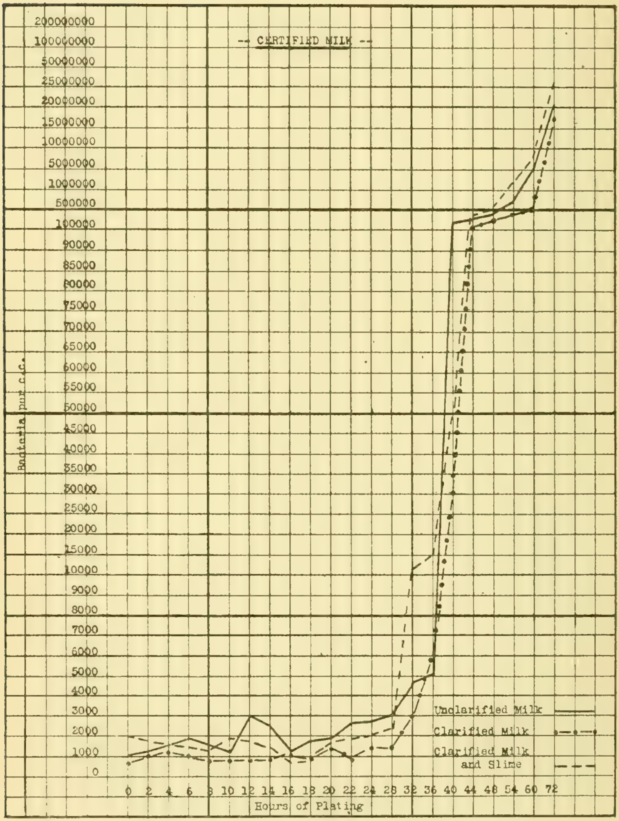
Hours of Plating
Unclarified Milk
Clarified Milk
Clarified Milk and Slime


-- CERTIFIED MILK --
Bacteria per c.c.
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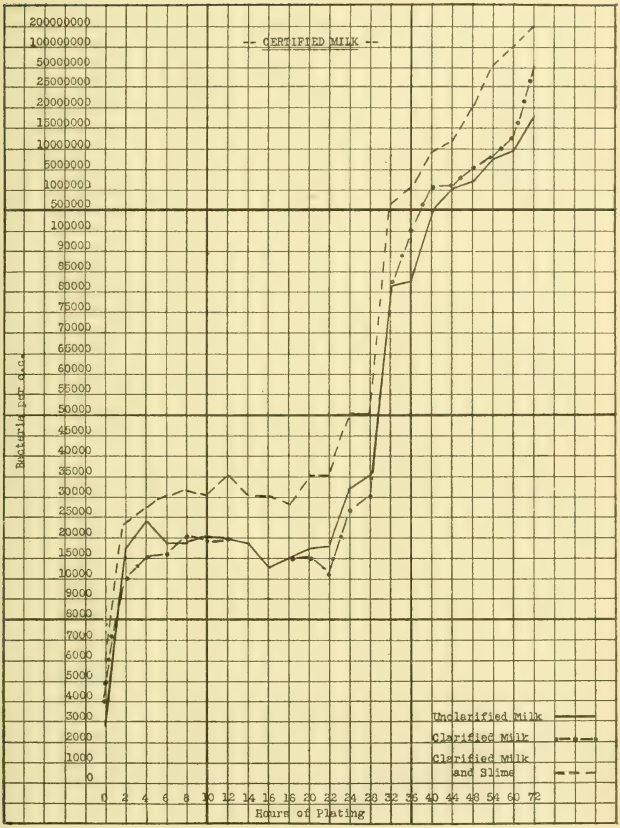
Hours of Plating
Unclarified Milk
Clarified Milk
Clarified Milk and Slime


-- CERTIFIED MILK --
Bacteria per c.c.
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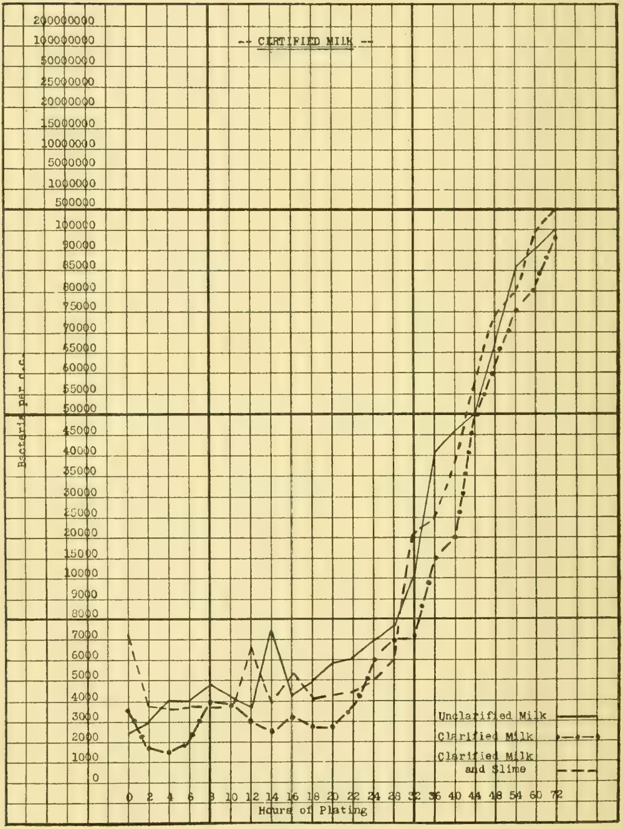
Hours of Plating
Unclarified Milk
Clarified Milk
Clarified Milk and Slime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Bacteria per c.c.
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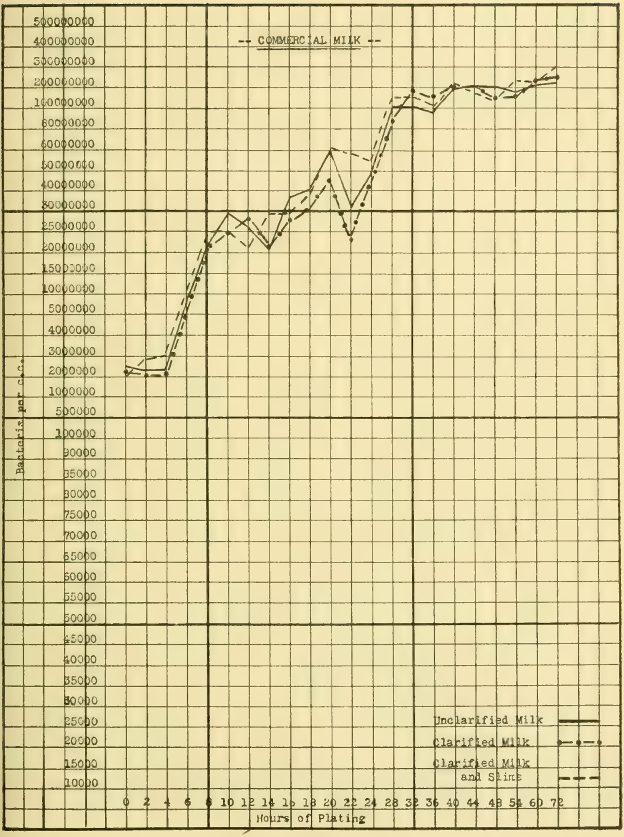
Hours of Plating
Unclarified Milk
Clarified Milk
Clarified Milk and Slime


-- COMMERCIAL MILK --
Bacteria per c.c.
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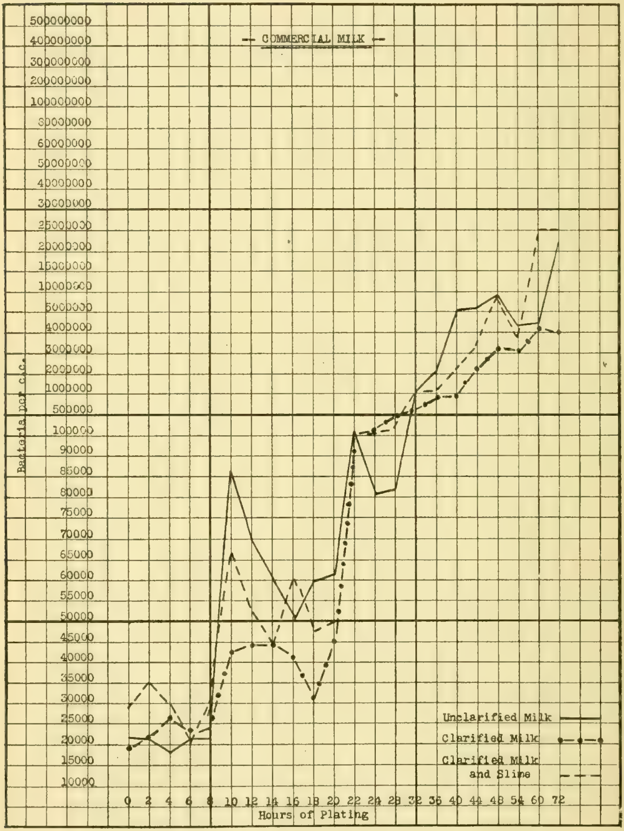
Hours of Plating
Unclarified Milk
Clarified Milk
Clarified Milk and Slime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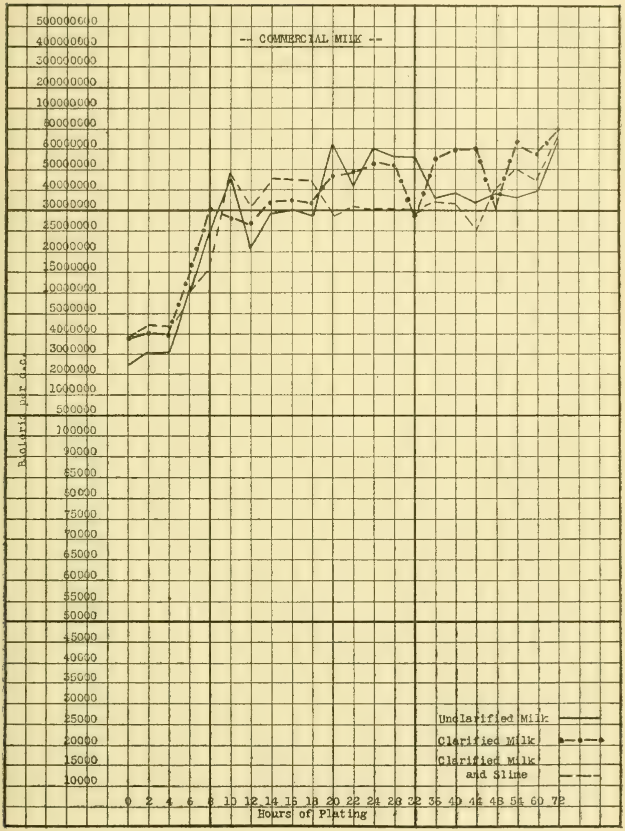
Bacteria per c.c.
0 2 4 6 8 10 12 14 16 18 20 22 24 28 32 36 40 44 48 54 60 72
Hours of Plating
Unclarified Milk
Clarified Milk
Clarified Milk and Slime


-- COMMERCIAL MILK --
Bacteria per c.c.
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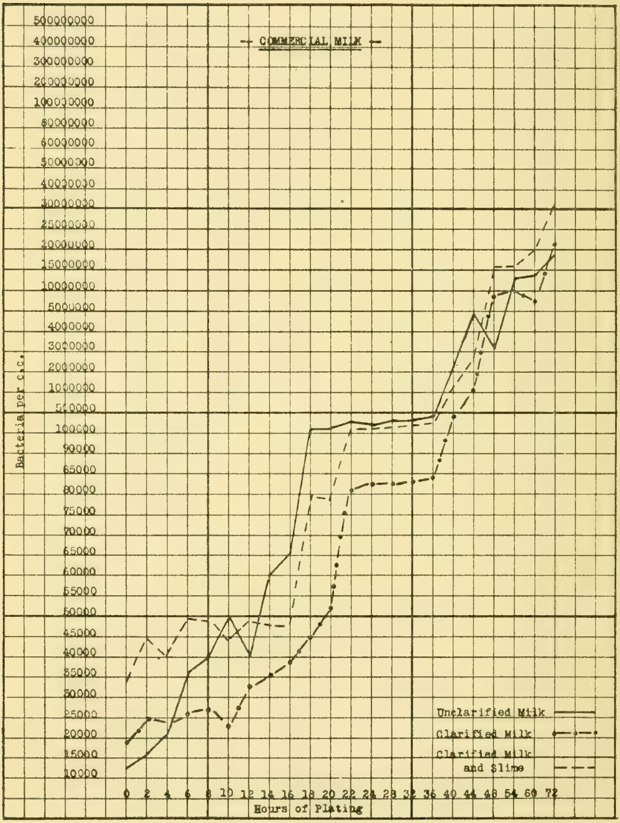
0 2 4 6 8 10 12 14 16 18 20 22 24 28 32 36 40 44 48 54 60 72
Hours of Plating
Unclarified Milk
Clarified Milk
Clarified Milk and Slime


-- COMMERCIAL MILK --
Bacteria per c.c.
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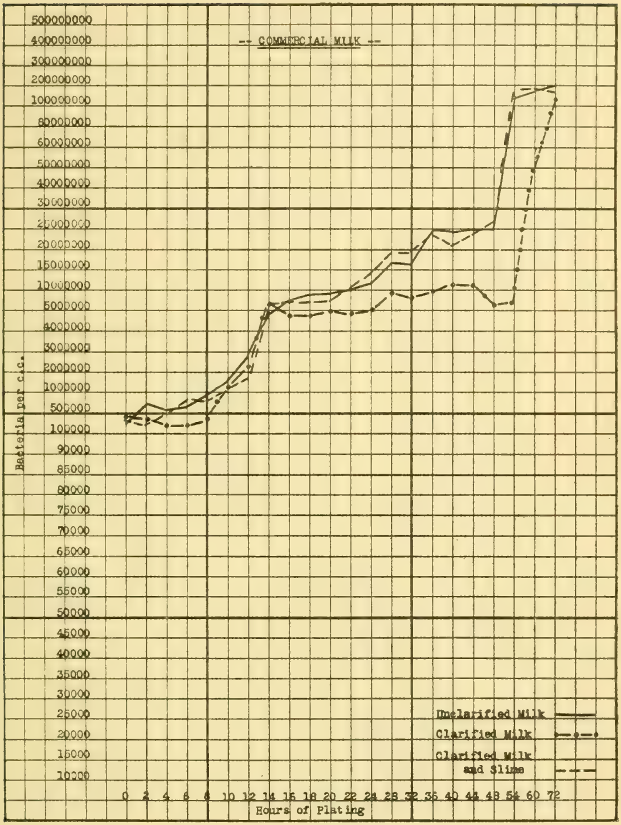
Hours of Plating
Unclarified Milk
Clarified Milk
Clarified Milk and Slime



The conclusion may be drawn from these graphs that there is no great distinction to be made between clarified and unclarified milk so far as bacterial counts are concerned. Yet when the character of change is contrasted, microbial influences are patent as between the unclarified and clarified samples.

Incidental questions having more or less relation to the previous discussion may arise. Some of these questions have been anticipated in our work, and have been added as illuminative material.

TABLE XLIV. — *A Determination of the Number of Bacteria per Cubic Centimeter in Clarified and Unclarified Commercial Milk Held at 14° C. and Plated at Intervals of Twenty-four Hours.*

TEST.	Sample.	At Once.	24 Hours.	48 Hours.	72 Hours.
I,	Before clarification,	3,600,000	1,750,000	5,600,000	250,000,000
	After clarification,	2,600,000	3,100,000	5,200,000	250,000,000
II,	Before clarification,	36,000	800,000	67,100,000	80,000,000
	After clarification,	34,000	525,000	50,600,000	40,000,000
III,	Before clarification,	3,600	–	4,100,000	7,500,000
	After clarification,	2,100	–	3,700,000	15,000,000
IV,	Before clarification,	28,000	9,958,000	210,000,000	350,000,000
	After clarification,	39,000	9,950,000	220,000,000	400,000,000
V,	Before clarification,	2,500	2,300	230,000	25,000,000
	After clarification,	2,350	3,200	190,000	39,000,000
VI,	Before clarification,	7,750,000	40,000,000	539,000,000	752,000,000
	After clarification,	6,340,000	27,400,000	465,000,000	441,000,000
VII,	Before clarification,	4,000,000	14,600,000	201,000,000	400,000,000
	After clarification,	2,740,000	19,600,000	209,000,000	187,000,000
VIII,	Before clarification,	500,000	20,400,000	120,000,000	237,000,000
	After clarification,	450,000	13,500,000	160,000,000	135,000,000
IX,	Before clarification,	330,000	14,500,000	41,200,000	166,000,000
	After clarification,	240,000	10,000,000	40,000,000	100,000,000
X,	Before clarification,	4,500,000	21,200,000	340,000,000	750,000,000
	After clarification,	4,000,000	19,200,000	210,000,000	450,000,000
XI,	Before clarification,	1,500,000	20,000,000	500,000,000	650,000,000
	After clarification,	1,200,000	25,000,000	420,000,000	560,000,000

TABLE XLV. — *A Determination of the Number of Bacteria per Cubic Centimeter in Clarified and Unclarified Certified Milk Held at 10° C. and Plated at Intervals of Twenty-four Hours.*

TEST.	Sample.	At Once.	24 Hours.	48 Hours.
I,	Before clarification,	940	1,000	900
	After clarification,	580	1,050	600
II,	Before clarification,	1,450	2,200	2,400
	After clarification,	4,200	3,700	4,600
III,	Before clarification,	1,800	1,740	2,000
	After clarification,	2,600	2,500	3,200
IV,	Before clarification,	980	1,150	1,000
	After clarification,	810	860	650
V,	Before clarification,	1,400	1,100	1,000
	After clarification,	1,200	1,750	1,200
VI,	Before clarification,	4,000	4,000	4,300
	After clarification,	3,000	3,100	2,500
VII,	Before clarification,	5,000	4,700	2,300
	After clarification,	4,000	5,000	1,400
VIII,	Before clarification,	3,000	2,300	3,500
	After clarification,	4,100	2,000	2,500

Incidentally only, it is interesting to note the effect of repeated clarification upon the same sample. From this it may be seen that neither the slime nor bacteria are removed to such an extent that repeated clarification will not eliminate more bacteria and more slime.

TABLE XLVI. — *Effect of Repeated Clarification on Bacterial Count of Same Sample of Market Milk.*

	Bacteria per Cubic Centimeter in Milk.	Weight of Slime in Grams.	SECOND CLARIFICATION.		THIRD CLARIFICATION.		FOURTH CLARIFICATION.	
			Bacteria per Cubic Centimeter.	Weight of Slime in Grams.	Bacteria per Cubic Centimeter.	Weight of Slime in Grams.	Bacteria per Cubic Centimeter.	Weight of Slime in Grams.
Before clarification, . .	50,000	3.122	74,000	1.379	48,000	1.236	40,000	.925
After clarification, . .	70,000	–	48,000	–	40,000	–	–	–
Before clarification, . .	7,000	2.091	25,000	1.002	11,000	.927	–	–
After clarification, . .	17,000	–	11,000	–	–	–	–	–
Before clarification, . .	25,000	3.265	9,000	1.315	22,000	.865	–	–
After clarification, . .	18,000	–	22,000	–	–	–	–	–

In connection with the single and serial bacterial counts it will be pertinent to study also the effect of clarification upon specific organisms in different substances, for in this manner a possibility is furnished of gaining some adequate notion of how the clarifier acts in centrifuging out certain types of organisms.

TABLE XLVII. — *Effect of Clarification on Pure Cultures of Bacteria.*

B. subtilis.

SUSPENDED IN —	Before Clarification.	After Clarification.	Result or Per Cent. Removed.
First Test.			
Water, ...	105,000	7,000	93.3
Broth (A. P. H. A.), ...	95,000	15,000	84.3
Skimmed milk, ...	107,000	48,000	55.2
Second Test.			
Water, ...	75,000	2,000	97.0
Broth (A. P. H. A.), ...	90,000	18,000	80.0
Skimmed milk, ...	95,000	25,000	74.0
Whole milk, ...	92,000	56,000	40.0

TABLE XLVII. — *Effect of Clarification on Pure Cultures of Bacteria* — Continued.

B. coli.

SUSPENDED IN —	Before Clarification.	After Clarification.	Result or Per Cent. Removed.
First Test.			
Water,	480,000	118,000	76
Broth (A. P. H. A.),	465,000	115,000	75
Skimmed milk,	495,000	375,000	28
Whole milk,	530,000	320,000	40
Second Test.			
Water,	370,000	90,000	76
Broth (A. P. H. A.),	395,000	135,000	66
Skimmed milk,	315,000	215,000	31
Whole milk,	400,000	280,000	30
B. cyanogenes.			
Water,	20,000	7,000	65
B. megatherium.			
Water,	10,000	3,000	70
B. subtilis.			
Water,	70,000	10,000	85
Gum tragic-water,	70,000	55,000	22

B. subtilis.

Specific Gravity.	SUSPENDED IN —	Before Clarification.	After Clarification.	Per Cent. Removed.
1.000	Water,	100,000	5,000	95
1.003	Water+1 per cent. gelatin,	138,000	25,000	82
1.005	Water+2 per cent. gelatin,	110,000	40,000	64
1.009	Water+4 per cent. gelatin,	120,000	48,000	60
	B. subtilis.			
1.000	Water,	65,000	3,000	95
1.003	Water+1 per cent. sucrose,	115,000	5,000	94
1.011	Water+3 per cent. sucrose,	126,000	13,000	89
1.023	Water+6 per cent. sucrose,	95,000	12,000	87
1.026	Water+8 per cent. sucrose,	103,000	18,000	83

TABLE XLVII. — *Effect of Clarification on Pure Cultures of Bacteria* — Continued.

Streptococcus pyogenes.

SUSPENDED IN —	Before Clarification.	After Clarification.	Per Cent. Removed.
First Test.			
Salt solution,	2,120,000	370,000	83
Whey solution,	1,750,000	550,000	68
Certified milk,	2,600,000	2,100,000	19
Second Test.			
Salt solution,	2,370,000	345,000	85
Whey solution,	2,000,000	850,000	59
Certified milk,	1,900,000	1,870,000	16
Third Test.			
Salt solution,	2,000,000	450,000	77
Whey solution,	1,750,000	700,000	60
Certified milk,	1,400,000	1,000,000	27

Staphylococcus albus.

First Test.			
Salt solution,	130,000	10,000	91
Whey solution,	175,000	44,000	75
Certified milk,	705,000	285,000	59
Second Test.			
Salt solution,	800,000	44,000	94
Whey solution,	420,000	143,000	66
Certified milk,	870,000	460,000	47
Third Test.			
Salt solution,	1,200,000	180,000	93
Whey solution,	400,000	82,000	79
Certified milk,	950,000	540,000	43

TABLE XLVII. — *Effect of Clarification on Pure Cultures of Bacteria* — Continued.

B. prodigiosus.

SUSPENDED IN —	Before Clarification.	After Clarification.	Per Cent. Removed.
First Test.			
Salt solution,	700,000	230,000	67
Whey solution,	400,000	170,000	57
Certified milk,	1,350,000	1,100,000	18
Second Test.			
Salt solution,	3,100,000	840,000	72
Whey solution,	2,290,000	1,250,000	45
Certified milk,	3,400,000	2,600,000	22
Third Test.			
Salt solution,	830,000	220,000	73
Whey solution,	2,000,000	1,400,000	30
Certified milk,	1,970,000	1,370,000	30

B. tumescens.

First Test.			
Salt solution,	22,500	3,000	71
Whey solution,	13,000	6,000	53
Certified milk,	22,000	12,500	43
Second Test.			
Salt solution,	31,000	6,000	80
Whey solution,	21,500	10,000	53
Certified milk,	32,000	10,000	68
Third Test.			
Salt solution,	40,000	3,000	92
Whey solution,	20,000	5,000	75
Certified milk,	77,000	16,000	79

TABLE XLVII. — *Effect of Clarification on Pure Cultures of Bacteria* — Concluded.

B. coli.

SUSPENDED IN —	Before Clarification.	After Clarification.	Per Cent. Removed.
First Test.			
Salt solution,	6,200,000	1,230,000	80
Whey solution,	4,590,000	4,300,000	6
Certified milk,	5,510,000	4,355,000	21
Second Test.			
Salt solution,	2,800,000	440,000	84
Whey solution,	1,800,000	1,600,000	11
Certified milk,	2,800,000	2,590,000	7
Third Test.			
Salt solution,	1,300,000	440,000	66
Whey solution,	1,650,000	1,270,000	23
Certified milk,	2,895,000	2,750,000	5

Streptococcus lacticus.

SUSPENDED IN —	Before Clarification.	After Clarification.	Per Cent. Removed.
First Test.			
Salt solution,	4,500,000	1,500,000	66
Whey solution,	3,500,000	1,300,000	63
Certified milk,	1,000,000	800,000	20
Second Test.			
Salt solution,	700,000	120,000	82
Whey solution,	720,000	60,000	91
Certified milk,	600,000	540,000	10
Third Test.			
Salt solution,	400,000	35,000	91
Whey solution,	430,000	70,000	82
Certified milk,	1,060,000	600,000	43

NOTE. — 1. *Salt Solution.* — Prepared by adding 8.5 grams of sodium chloride to 1,000 cubic centimeters of distilled water. Sterilized by autoclaving at 15 pounds for thirty minutes.

2. *Whey Solution.* — Prepared from whey secured from the college dairy. Egg albumin was added to the whey, and heated for two hours in the flowing steam. It was then filtered clear through filter paper. To this was added 1 per cent. of bacto-gelatin and sterilized intermittently.

3. *Certified Milk.* — Fresh certified milk secured from the college herd.

4. In each of the experiments 1,000 cubic centimeters of the material was employed. The pure culture under test was added directly from a twenty-four-hour milk or broth culture, after the quantity of culture to be used had been determined.

5. The specific gravity and viscosity of the whey menstruum were approximately that of certified milk, as determined by preliminary experiments with pyknometer and viscosimeter.

6. Room temperature in which experiments were conducted varied from 19° to 23° C., so that clarification was conducted within this range of temperature.

TABLE XLVIII. — *Effect of Clarification on Pure Cultures of Molds and Yeasts.*

Rhizopus nigricans spores.

TEST NO.	BEFORE CLARIFICATION.	AFTER CLARIFICATION.	
	100 Dilution.	100 Dilution.	1,000 Dilution.
1	10, or 1,000 per cubic centimeter,	1, or 100 per cubic centimeter,	Sterile.
2	30, or 3,000 per cubic centimeter,	Sterile,[1]	Sterile.
3	11, or 1,100 per cubic centimeter,	Sterile,	Sterile.

Penicillium glaucum spores.

1	10, or 1,000 per cubic centimeter,	Sterile,	Sterile.
2	40, or 4,000 per cubic centimeter,	1, or 100 per cubic centimeter,	Sterile.
3	20, or 2,000 per cubic centimeter,	2, or 200 per cubic centimeter,	Sterile.

Oidium lactis spores.[2]

TEST NO.	BEFORE CLARIFICATION.	AFTER CLARIFICATION.	
	1,000 Dilution.	100 Dilution.	1,000 Dilution.
1	14, or 14,000 per cubic centimeter,	Sterile,	Sterile.
2	24, or 24,000 per cubic centimeter,	4, or 400 per cubic centimeter,	Sterile.
3	11, or 11,000 per cubic centimeter,	1, or 100 per cubic centimeter,	Sterile.

Saccharomyces cerevisiæ.

1	200, or 200,000 per cubic centimeter,	1, or 100 per cubic centimeter,	Sterile.
2	370, or 370,000 per cubic centimeter,	1, or 100 per cubic centimeter,	Sterile.
3	120, or 120,000 per cubic centimeter,	3, or 300 per cubic centimeter,	Sterile.

Aspergillus niger spores.

1	16, or 16,000 per cubic centimeter,	6, or 600 per cubic centimeter,	Sterile.
2	7, or 7,000 per cubic centimeter,	4, or 400 per cubic centimeter,	Sterile.
3	5, or 5,000 per cubic centimeter,	1, or 100 per cubic centimeter,	Sterile.

NOTE. — Molds were grown in pure culture; spores were swept up with sterile filter paper and introduced into 1,000 cubic centimeters of sterile milk. After thorough agitation milk was clarified under sterile conditions. Counts were made immediately before and after.

Cultures of *Saccharomyces cerevisiæ* were grown on wort medium at room temperature for three days; 5 cubic centimeters of the culture were inoculated directly into 1,000 cubic centimeters of sterile milk. After thorough agitation, milk was clarified under sterile conditions. Counts were made immediately before and after.

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[1] "Sterile" means that no colonies appeared when plates were made of the dilutions indicated.

[2] Oidium was grown directly in sterile milk at room temperature for three days, until small colonies appeared on surface.

TABLE XLIX. — *Effect of Three Clarifications on Pure Cultures.*

Streptococcus pyogenes.

SUSPENDED IN —	FIRST CLARIFICATION.		SECOND CLARIFICATION.		THIRD CLARIFICATION.		Per Cent. Removed.
	Before.	After.	Before.	After.	Before.	After.	
First Test.							
Salt solution, . .	2,120,000	370,000	370,000	80,000	80,000	14,000	99
Whey solution, . .	1,750,000	550,000	550,000	250,000	250,000	75,000	95
Certified milk, . .	2,600,000	2,100,000	2,100,000	–	–	800,000	69
Second Test.							
Salt solution, . .	2,370,000	345,000	345,000	78,000	78,000	15,500	99
Whey solution, . .	2,000,000	850,000	850,000	325,000	325,000	100,000	95
Certified milk, . .	1,900,000	1,870,000	1,870,000	1,200,000	1,200,000	900,000	52
Third Test.							
Salt solution, . .	2,000,000	450,000	450,000	95,000	95,000	22,500	98
Whey solution, . .	1,750,000	700,000	700,000	370,000	370,000	110,000	93
Certified milk, . .	1,400,000	1,000,000	1,000,000	600,000	600,000	400,000	71

Staphylococcus albus.

SUSPENDED IN —	FIRST CLARIFICATION.		SECOND CLARIFICATION.		THIRD CLARIFICATION.		Per Cent. Removed.
	Before.	After.	Before.	After.	Before.	After.	
First Test.							
Salt solution, . .	130,000	10,000	10,000	1,200	1,200	100	99
Whey solution, . .	175,000	44,000	44,000	7,500	7,500	1,600	99
Certified milk, . .	705,000	285,000	285,000	147,000	147,000	56,000	92
Second Test.							
Salt solution, . .	800,000	44,000	44,000	3,300	3,300	200	99
Whey solution, . .	420,000	143,000	143,000	31,000	31,000	3,600	99
Certified milk, . .	870,000	460,000	460,000	260,000	260,000	126,000	85
Third Test.							
Salt solution, . .	350,000	31,000	31,000	1,500	1,500	100	99
Whey solution, . .	400,000	82,000	82,000	21,000	21,000	4,000	99
Certified milk, . .	950,000	540,000	540,000	350,000	350,000	75,000	92

TABLE XLIX. — *Effect of Three Clarifications on Pure Cultures* — Continued.

B. tumescens.

SUSPENDED IN —	FIRST CLARIFICATION.		SECOND CLARIFICATION.		THIRD CLARIFICATION.		Per Cent. Removed.
	Before.	After.	Before.	After.	Before.	After.	
First Test.							
Salt solution, . .	31,000	20,000	20,000	1,000	1,000	70	99
Whey solution, . .	20,000	2,000	2,000	6,000	6,000	60	99
Certified milk, . .	33,000	70,000	70,000	8,400	8,400	4,100	87
Second Test.							
Salt solution, . .	22,500	3,000	3,000	1,000	1,000	550	93
Whey solution, . .	13,000	6,000	6,000	500	500	150	98
Certified milk, . .	32,000	10,000	10,000	2,500	2,500	1,300	96
Third Test.							
Salt solution, . .	40,000	3,000	3,000	750	750	200	99
Whey solution, . .	20,000	5,000	5,000	600	600	500	97
Certified milk, . .	77,000	16,000	16,000	4,800	4,800	2,400	97

B. coli.

First Test.							
Salt solution, . .	6,200,000	1,230,000	1,230,000	350,000	350,000	90,000	98
Whey solution, . .	4,590,000	4,300,000	4,300,000	1,850,000	1,850,000	660,000	83
Certified milk, . .	5,510,000	4,355,000	4,355,000	4,000,000	4,000,000	3,625,000	32
Second Test.							
Salt solution, . .	2,800,000	440,000	440,000	210,000	210,000	50,000	98
Whey solution, . .	2,775,000	2,375,000	2,375,000	1,130,000	1,130,000	430,000	84
Certified milk, . .	2,800,000	2,590,000	2,590,000	2,400,000	2,400,000	1,900,000	32
Third Test.							
Salt solution, . .	1,300,000	440,000	440,000	62,000	62,000	26,000	98
Whey solution, . .	1,650,000	1,270,000	1,270,000	620,000	620,000	320,000	80
Certified milk, . .	870,000	1,700,000	1,700,000	950,000	950,000	750,000	14

TABLE XLIX. — *Effect of Three Clarifications on Pure Cultures* — Concluded.

B. prodigiosus.

SUSPENDED IN —	FIRST CLARIFICATION.		SECOND CLARIFICATION.		THIRD CLARIFICATION.		Per Cent. Removed.
	Before.	After.	Before.	After.	Before.	After.	
First Test.							
Salt solution,	144,000	14,000	14,000	13,000	13,000	1,600	91
Whey solution,	153,000	99,000	99,000	24,100	24,100	15,000	90
Certified milk,	1,100,000	1,100,000	1,100,000	600,000	600,000	420,000	61
Second Test.							
Salt solution,	700,000	230,000	230,000	82,000	82,000	17,000	97
Whey solution,	400,000	170,000	170,000	90,000	90,000	47,000	88
Certified milk,	1,350,000	1,100,000	1,100,000	800,000	800,000	550,000	59
Third Test.							
Salt solution,	830,000	220,000	220,000	75,000	75,000	30,000	96
Whey solution,	2,000,000	1,400,000	1,400,000	630,000	630,000	340,000	83
Certified milk,	1,970,000	1,370,000	1,370,000	1,312,000	1,312,000	796,000	59

Streptococcus lacticus.

First Test.							
Salt solution,	4,500,000	1,500,000	1,500,000	375,000	375,000	125,000	97
Whey solution,	3,500,000	1,300,000	1,300,000	1,000,000	1,000,000	400,000	88
Certified milk,	1,000,000	800,000	800,000	360,000	360,000	300,000	70
Second Test.							
Salt solution,	700,000	120,000	120,000	36,000	36,000	8,400	98
Whey solution,	720,000	60,000	60,000	20,000	20,000	1,500	99
Certified milk,	600,000	540,000	540,000	300,000	300,000	80,000	86
Third Test.							
Salt solution,	400,000	35,000	35,000	12,000	12,000	1,200	99
Whey solution,	430,000	70,000	70,000	40,000	40,000	10,000	97
Certified milk,	1,060,000	600,000	600,000	60,000	60,000	50,000	95

TABLE L. — *Streptococci Suspended in Milk Subjected to Clarification.*

I.	Bacterial count of whole milk before adding streptococci.	Before clarification,	33,000	51 per cent. decrease.
		After clarification,	16,000	
	Bacterial count of same milk after adding streptococci.	Before clarification,	29,000,000	24 per cent. increase.
		After clarification,	36,000,000	
II.	Bacterial count of whole milk before adding streptococci.	Before clarification,	75,000	60 per cent. increase.
		After clarification,	120,000	
	Bacterial count of same milk after adding streptococci.	Before clarification,	2,000,000	80 per cent. increase.
		After clarification,	3,700,000	

COLONIZATION OF BACTERIA IN MILK.

Little can be stated with any degree of assurance concerning colonization of bacteria in milk. That colonization occurs, and that the degree of colonization is irregular in different milks, can be attested in several ways. One of these methods is set forth in what might be wisely designated as the provisional conclusions offered by many of the workers who have determined the number of bacteria before and after clarifying, assuming that the increased count is due to the breaking up of the colonies formed. This is, of course, indirect evidence, and must be regarded as tentative until something more direct can be provided. Little is known of a definite character concerning what bacteria will do in this respect, so that any conclusions based upon this precarious factor may go far astray. Knowledge of exact value upon this subject is almost entirely lacking. Again, the tendency of bacteria to grow into colonies is daily recognized, and yet there are conditions of cultures which do not favor such developments. What can be said about milk, and to what extent does the colony vitiate our crude plating methods and our comfortable conclusions based on them? This is important and is made conspicuous by a shroud of ignorance.

EFFICIENCY OF THE INDIVIDUAL ORGANISM FREE AND IN COLONY.

This leads to the next step, which is also of significance. Does the individual organism in a colony exercise the same degree of physiological efficiency as when the organism is alone and acting in an individual rôle? We are told by McInerney[1] that bacteria increased more rapidly in unclarified than in clarified milk, yet a greater degree of change, as the production of acid, is recorded in the milk influenced by clarification than in the check culture unclarified and uninfluenced. This also occurs in a pure culture of lactic bacteria when shaken. This suggests, possibly, that per individual the clarified culture is doing greater work. What values shall be attached to the individual germ free as against the same germ in a colony? This we must know if we are going to interpret milk clarification, provided the present explanation which accounts for the increased number of bacteria after clarification is tenable. At present our knowledge is too restricted to draw stable conclusions.

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[1] McInerney, T. J.: Clarification of Milk. Cornell Univ. Agr. Exp. Sta. Bulletin No. 389, April, 1917.

Other Considerations.

Centrifugal force has been repeatedly and commonly employed to eject micro-organisms when in suspension, which is the case in hand. Its values for this purpose are in a very general way understood. From the largest micro-organism with limited surface as compared with its content, to the minutest with its extensive surface as compared with its content, there seems to exist a gradation in effectiveness. In other words, the large organisms are easily ejected, while the minutest are with difficulty cast out. In the case of some of the invisible viruses the capacity to produce disease is not reduced materially by centrifugalization. In the foregoing tables it is apparent that the larger micro-organisms, as the spores of *Oidium lactis* and the cells of *Sacch. cerevisiæ*, respond readily to centrifugal force, while such organisms as *B. prodigiosus* respond poorly. Likewise, colonies seemingly act as large and small cells. Again, it is well known that micro-organisms contain a variable amount of fat, as *B. tuberculosis*. Fat is easily determined, too, in varying amounts in mold and yeast cells when subjected to certain conditions of growth. The presence of fat must influence the specific gravity of cells, which in turn is closely related to results from centrifugalization. The age of a microbial cell, or the stage of development, is also bound up with its specific gravity, due probably to the degradative changes taking place. This is easily seen in the development of a culture when the old cells settle to the bottom.

It is very evident from physical laws that the material in which micro-organisms are suspended has a very important and peculiar influence in their sedimentation by mechanical force. Milk, with its higher specific gravity and viscosity, acts as a deterrent in the removal of micro-organisms by centrifugalization, as is clearly evidenced by the preceding tables for specific organisms. In spite of deterrent influences referred to, micro-organisms are removed from milk in as large quantities as 75 per cent. and over. Inasmuch as the plate colony-counts probably represent colonies removed from milk, the percentage may rise much higher. The results presented in the preceding tables, in which the work of the clarifier upon specific organisms is shown, have an illuminating bearing on the action of the clarifier in its practical application to market milk.

In considering micro-organisms in milk it is necessary to remember the "ebb and flow" of species. All who are students of milk have learned that in the course of fermentation-development certain types of micro-organisms in milk gradually reach the crest of their growth then gradually decline in numbers, as the rise and fall in numbers of the many species which are present in fresh milk, and which practically disappear as conditions change. This is also discernible in the ascendency and decline of the lactic group followed by other types which appear and disappear, leading finally to complete decomposition of the milk. This "special growth-curve" which appears when conditions are favorable is a factor in clarification, for by this mechanical act the conditions for microbial development are apparently somewhat altered, and accordingly there is resulting a more or less kaleidoscopic change. It follows, therefore, that an additional factor to those already controlling the stages of alteration or fermentation in milk has been introduced, naturally yielding somewhat different changes in the course of milk fermentation.

The removal of large numbers of bacteria by clarification, as has been established, must exert some influence upon the changes which take place in the clarified milk. Especially will this be true if the types which yield more readily to centrifugalization are cast out in large numbers and the types which seem to respond but poorly remain behind. The balance of growth equilibrium is disturbed. When conditions of growth are so complex as in milk, it can at once be surmised that owing to the great variation in the germ-content of milk, both in numbers and kinds, the results must be widely different. It seems that there ought to be evidence which will correlate this great change in germ-content with alterations in clarified milk as different from unclarified. It will not be possible to furnish all of our data at the present writing. Only such evidence as has led us into a more intimate study of these changes will be given.

When unclarified and clarified milk of the same original sample is permitted to stand for some time at low temperature (15° C.), so that the fermentation changes appearing do not rush by unnoticed, visible alterations are evident. The precipitated casein resulting from such a fermentation may be collected then on a sterilized filter paper, and, after covering carefully, allowed to stand at ordinary temperatures for some time. The difference in the fermentation changes of the unclarified and clarified milk casein is usually strikingly manifest. This demonstrates that in the unclarified milk and casein there exist organisms which preponderate over those in the clarified milk and casein. Hence the clarifier has ejected certain types of organisms in sufficient numbers to control the character of the fermentation in the clarified milk and casein. Whether these changes can be explained by the elimination of *Oidium lactis* and other molds and yeasts (see page 234) cannot be definitely stated at present.

These observations have induced us into undertaking to demonstrate the factors involved in these differences. To this task our energies have been directed, and some of the data are at present available, but it is felt that the answer should be given as a single answer and as completely as possible.

IV. SUMMARY.

1. It is evident that our present knowledge of clarification does not enable us to reach a scientific interpretation.

2. An intimate study of clarification not only reveals facts which assist in its understanding, but also leads us into depths beyond our reach. It is constantly presenting suggestions concerning milk investigations which have not been considered heretofore through established channels. A fertile field for research is opened.

3. The slime eliminated and the comparison of the clarified milk with the unclarified seem to offer, at the present time, the best approach to the study of clarification.

4. The amount of slime eliminated from milk is variable, and dependent upon —

The condition of the cow, whether normal or abnormal.
The period of lactation.
The age or freshness of the milk.
The acidity of the milk.
The temperature at the time of clarifying.
The amount of corpuscular elements.
The amount of insoluble dirt in the milk.

5. The food value removed from milk through the elimination of slime may be disregarded, unless there are contained within some of the elements of the slime nutritional activators, as the so-called vitamines, which seems improbable.

6. Masses of cells are thrown out in the slime. This is especially emphasized when any inflammation exists in the udder. Garget, existing as it does in ropy, tenacious form, is completely ejected. What significance is to be attached to normal cells, so far as the authors are concerned, cannot be stated from our present knowledge.

7. A fibrinous material responding to fibrin stains is practically wholly eliminated from milk in clarification.

8. Practically all insoluble dirt is removed in clarification. The clarifier is the most effective strainer employed in the diary. Its efficiency in this respect is greater than that of the cotton filters of the Wisconsin Sedimentation Tester. Dirt in solution, of course, is not subject to the action of a centrifuge or clarifier, inasmuch as it diffuses throughout the whole mass.

9. Micro-organisms are found in large numbers — yes, in masses — in the slime. These come from the milk, since there is no other source, and there is not sufficient time to multiply while passing through the clarifier. In certified milk there is also a reduction shown after clarification, as revealed by the plating method. In market milk the number is usually increased after clarification, as revealed by the plating method. This is doubtless due to the disruption of colonies. Besides the above evidence there are the results of repeated clarification of milk and pure cultures,

the action of clarification upon pure cultures, and the results secured by direct counts, — all of which testify to the elimination of micro-organisms by the clarifier in no small degree. No differentiation between pathogens and non-pathogens can be made. The larger the micro-organisms, speaking generally, the greater the proportion cast out.

10. Frequently, yes, commonly, the action of the clarifier upon the micro-organisms is so significant as to alter their respective power or capacity for change in the milk. This is easily detectable by the appearance of clarified and unclarified samples when observed from day to day over a period of time. It is also readily determined by filtering out the curd, when formed, upon filter paper, and allowing it to undergo fermentation for a few days under proper conditions.

In Part II we shall consider this alteration in clarified milk as compared with unclarified milk. The work has progressed to a point that it is safe and only fair to say that an intimate study is confirming the general statements above.

BULLETIN No. 188 DECEMBER, 1918

MASSACHUSETTS
AGRICULTURAL EXPERIMENT STATION

THE NUTRITION OF THE HORSE

By J. B. LINDSEY

Part I of this bulletin contains very brief conclusions of many important investigations conducted chiefly by French and German scientists.

The results of the earlier work (previous to 1890) were based largely upon the relation of digestible nutrients to maintenance and work performed, while that of more recent times has been based to a greater extent upon the application of calorimetry to the intake and outgo of energy.

Part II of the bulletin contains the practical conclusions of feeding experiments with alfalfa, brewers' dried grains, velvet bean feed and linseed meal, together with suitable combinations for work horses when these feeds are used as components of the ration. A full description of the feeding trials follows the general conclusions.

Requests for bulletins should be addressed to the
AGRICULTURAL EXPERIMENT STATION,
AMHERST, MASS.

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Publication of this Document
approved by the
Supervisor of Administration.

BULLETIN No. 188.

DEPARTMENT OF CHEMISTRY.

THE NUTRITION OF THE HORSE.

BY J. B. LINDSEY.

PART I.

SOME RESULTS OF IMPORTANT INVESTIGATIONS.

A. EARLY INVESTIGATIONS.

Much work has been done, especially in Europe, concerning the principles which underlie the nutrition of the horse, and many experiments made to test the practical application of the knowledge secured. Among the Europeans who have studied these matters most thoroughly may be mentioned Boussingault; Baudement; Sanson; Grandeau, LeClerc, Ballancey and Alikan; Lavalard; Müntz and Gerard; Wolff and Kellner; Züntz, Hagermann and Lehmann. In the United States many experiments have been made concerning the most suitable feeds and feed combinations for horses. Worthy of especial mention is the one conducted by McCambell of the Kansas Experiment Station[1] with the government horses at Fort Riley.

The early investigations were based largely on the analysis and digestibility of the feeds fed and the relation of digestible nutrients to maintenance and work performed. Some of the more important conclusions, including particularly the modifications of rations and methods of feeding are mentioned below.

1. Of the total food consumed, $\frac{5}{12}$ is needed for maintenance in a state of repose, $\frac{4}{12}$ for bodily repair, and $\frac{3}{12}$ for work performed; or $\frac{5}{12}$ for maintenance in repose and $\frac{7}{12}$ for bodily repair and work. (Grandeau-Lavalard.)
2. Work of Grandeau and his associates, 1882–94.
   - (*a*) Maize was utilized in varying proportions with oats, depending upon the time of year and relative cost.
   - (*b*) Straw was gradually substituted for hay, followed finally by the complete removal of the hay.
   - (*c*) Beans were fed in place of brewery by-products.

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[1] Bul. No. 186, Kans. Exp. Sta.

(*d*) Limited amounts of oil cakes were used in the ration.

(*e*) The nutritive ratio was widened from 1:4.5 to 1:7.1.

(*f*) Glucose was found to be completely digested; starch, from 76 to 98 per cent.; cellulose that could be hydrolyzed, from 40 to 68 per cent.; and crude cellulose, from 32 to 58 per cent.

(*g*) The average horse of 1,000 pounds needed for —

Maintenance, at rest, .76 pound of digestible protein plus 8.8 pounds of carbohydrates (including fat multiplied by 2.4) which contains 15,000 to 16,000 calories and has a nutritive ratio of 1:10 to 1:11.

Maintenance and repair, 1 pound digestible protein plus 9.9 pounds digestible carbohydrates (including fat multiplied by 2.4) which contains 20,000 calories and has a nutritive ratio of 1:10.

Light Work, 1.3 pounds digestible protein and 11.6 pounds digestible carbohydrates (including fat multiplied by 2.4) which contains some 25,000 calories having a nutritive ratio of 1:7. This amount is sufficient for horses doing 500,000 kilogrammeters of work daily.

3. Experiments in the French army.

The following nutrients were found to be needed per 1,000 pounds of live weight as a result of experiments made by military officers on French army horses in 1887–89, the ration being composed largely of oats and hay: —

Time of peace, 1.1 pounds digestible protein plus 10.8 pounds digestible carbohydrates, having a nutritive ratio of 1:9.

Time of war, 1.35 pounds digestible protein plus 10.8 pounds digestible carbohydrates; nutritive ratio of 1:8.

4. Lavalard found that omnibus and hack horses needed 1.45 pounds digestible protein plus 10.4 pounds digestible carbohydrates; nutritive ratio of 1:7 per 1,000 pounds live weight.

5. A few of Wolff's conclusions may be mentioned (1876–85).[1]

(*a*) For maintenance of a 1,100-pound horse on hay alone, 23.1 pounds were required containing 1.26 pounds of digestible protein and 9.25 pounds of total digestible organic nutrients, with a nutritive ratio of 1:6.3.

(*b*) An average day's work for a farm or draft horse of 1,100 pounds, in good condition, is 2,000,000 kilogrammeters, which requires 5.09 pounds of digestible nutrients plus 9.25 pounds for maintenance, or a total of 14.34 pounds containing 1.90 pounds protein and having a ratio of 1:6.6.

(*c*) When fed an average quantity of hay exclusively, a 1,100-pound horse cannot take over 26.4 pounds, and can do but little work on such a diet. The addition of some clover hay enables the horse to do about one-fourth of a day's work, while if given a full diet of alfalfa, 26 pounds, the horse is able to do fully one-half an average day's work.

(*d*) The ordinary food for the work horse is like amounts of hay and oats (13 pounds of hay and 13 pounds of oats for a 1,100-pound horse). The proportions of each can be varied, depending upon the amount of the work required.

(*e*) The carbohydrates furnish the chief source of heat and energy for the horse.

(*f*) One kilo of oats (2.2 pounds) added to a work ration enabled the horse to do substantially 530,400 kilogrammeters more of work, and 1 kilo of maize, 700,000 kilogrammeters. Maize proved a very satisfactory food to improve the weight and appearance of the horse.

(*g*) The horse bean when fed in an amount not exceeding 2 pounds daily proved quite satisfactory as a source of increased protein in the ration, but as a source of energy it hardly equaled oats.

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[1] **Grundlagen f. d. rationelle Fütterung des Pferdes, 1886.**

The above results and others that could be cited were based largely upon digestible nutrients in the foods fed and their relation to work performed, and did not take into consideration the energy expended in digesting the different kinds of feeds resulting in the loss of varying amounts of heat, nor the heat radiation resulting from the increased metabolism caused by certain feedstuffs.

B. Recent Investigations and the Application of Calorimetry.

The development and application of calorimetry, and its use in studying the intake and outgo of energy, has proved of great help in increasing our knowledge of the principles of nutrition and the nutritive value of animal feeds. The following calorimetric units and methods are employed in measuring the utilization of energy: —

(*a*) *The Calorie.* — The heat which is given off by a food when combined with or burned in oxygen is the measure of its total energy. The unit of energy is termed the calorie, and represents the amount of heat required to raise 1 kilogram of water 1° C. (Armsby has recently introduced the term therm, or larger unit, meaning the amount of heat necessary to raise 1,000 kilograms of water 1° C.) According to Stohman, Berthelot and Rübner the heat units, or number of calories, in 1 gram of protein or carbohydrates are 4.1, and in fat, 9.3, and the total energy of a food is the amounts of protein and carbohydrates multiplied by 4.1, and of fat multiplied by 9.3.

(*b*) *The Kilogrammeter.* — This represents the mechanical equivalent of a definite amount of heat, and is equal to the energy required to raise 1 kilogram of water 1 meter high.

A calorie of heat is equivalent in mechanical energy to that required to raise 427 kilograms 1 meter high (or 427 kilogrammeters), and this unit is called kilogram-calorie.

To convert digestible protein, carbohydrates and fat into kilogrammeters, multiply the grams of protein or carbohydrates by 4.1, and the fat by 9.3, and these products by 427.

(*c*) *The Respiratory Quotient.* — The relation of the oxygen consumed to the carbon dioxide given off has been termed by Pflüger the respiratory quotient, and is determined by dividing the volume of the carbon dioxide by the volume of oxygen.

In case of carbohydrates, glycogen, starch and sugar, the coefficient is equal to 1; in case of albuminoids, .729;[1] of fat, .700; and of alcohol, .666.

An animal in a state of repose consumes a definite amount of oxygen in the breaking up or burning of the food, and gives off a definite amount of carbon dioxide, the measurement of which forms a basis for the food required for maintenance. The consumption of oxygen and the exhalation of carbon dioxide are rapidly increased the moment any work is performed. This method has been used with the horse by introducing tubes into the trachea and measuring at intervals the intake and outgo of the respiratory gases.

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[1] After Lavalard, already cited, p. 123; according to Kellner, p. 75, .765.

(*d*) *The Respiration Calorimeter.* — The apparatus consists of an air-tight room in which the animal is placed for different periods of time, and, in addition to collecting the feces and urine, the carbon dioxide exhaled and the heat radiated are accurately measured. It has been employed particularly in nutrition experiments with man, neat cattle, dogs and even smaller animals.

An illustration of the value of the calorimetric method over chemical analysis and digestibility may be cited in the experiment conducted by Wolff, who found that a horse weighing 500 kilograms (1,100 pounds) required 6 kilos of oats and 6 kilos of hay, equivalent to 5,547 grams of digestible organic nutrients (minus fiber), to keep him in a state of maintenance and to enable him to perform 1,450,000 kilogrammeters of work. Of these nutrients 3,551 grams were necessary for maintenance, leaving 1,996 grams available for work. This amount — 1,996 grams — is equivalent to 3,478,030 kilogrammeters of work (1,996 multiplied by 4.1 calories equals 81,836 calories, which, multiplied by 425, equals 3,478,030), whereas the work actually performed was 1,450,000 kilogrammeters, or 41.7 per cent. Even this percentage was found by other experimenters to be too high, and is explained on the ground that the horse was particularly accustomed to such work. Züntz and Lehmann, by the use of the respiratory quotient, found that the percentage of similar work in relation to digestible nutrients was reduced to 26 per cent., and Laulonie, by the same method, secured 22 per cent. In other words, after the maintenance requirement is satisfied, the horse seems to be able to make use of about 25 per cent. of the remaining energy in the form of a definite kind of work (net efficiency of the animal, Armsby).

It has been found further by Züntz and Hagermann, in an extended series of experiments, that the net efficiency of food in case of the horse varies widely, depending upon the character of the work performed. Thus, in case of walking without a load, the average efficiency was 35 per cent.; in different grades of ascent, at a walk without a load, from 33.7 to 36.2 per cent.; and with a load, 22.7 per cent. In case of work at a slow trot without a load the net efficiency was 31.96 per cent., and with a load, from 23.4 to 31.7 per cent. On the basis of these studies formulas have been worked out for the amount of food required for definite kinds of work, but it is hardly practicable to employ them under conditions ordinarily prevailing.

By this method of procedure Züntz has determined the net energy value of a number of foods for the horse, and the results have led to a reduction in the amount of coarse food supplied, and an increase in the amount of concentrates, thus requiring the animal to expend less energy in mastication and digestion, and to care for less inert matter in the intestinal tract. A former ration for the bus horses of Paris, composed of oats, corn, beans, bran, hay and straw, contained 18.5 kilos of dry matter, while a ration based on the results of recent investigations, composed of oats, corn, beans, molasses and chopped straw, contained only 12.5 kilos of dry matter, and proved to be less cumbersome, furnished a like amount of energy, caused less digestion disturbances and was more economical.

C. SUMMARY OF INVESTIGATIONS.

The many investigations made, some of which have been mentioned, have led to a number of important practical deductions concerning the nutrition of the horse which are stated below.

1. Horses need a definite amount of nutrients per 1,000 pounds of live weight for maintenance, and an extra quantity for work. This amount depends upon the size and temperament of the horse and the character and extent of the work performed.

2. In addition to the data already presented, the following recent statements by Kellner and Armsby concerning the nutrients and energy requirements of the horse are worthy of especial mention: —

For Horses of 1,000 Pounds' Live Weight (Kellner).

	Light Work.	Medium Work.	Hard Work.
Dry matter (pounds),	18–23	21–26	23–28
Protein,	1.0	1.4	2.0
Fat,	.4	.6	.8
Carbohydrates,	9.8	11.3	13.7
Total (fat × 2.2),	11.7	14.0	17.5
Starch equivalent,	9.2	11.6	15.0

For Horses of 1,000 Pounds' Live Weight (Armsby).

	Light Work (2 Hours).	Medium Work (4 Hours).	Hard Work (8 Hours).
Digestible protein,	1.0	1.4	2.0
Net energy (therms),	7.6	11.1	18.2

Armsby adopts Kellner's protein standards and substitutes therms of energy for the customary fat and carbohydrates, or starch equivalent. He bases his knowledge of therms of net energy in feeding stuffs[1] utilized by horses largely on the work done by Züntz and Hagermann. The feeding stuffs used by these experimenters were comparatively few in number.

3. Fat should not be supplied to horses to a greater extent than is recommended for dairy animals, and 1 pound per 1,000 pounds of live weight should be regarded as the extreme amount.

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[1] The Nutrition of Farm Animals, by H. P. Armsby, p. 721.

4. The proportion which the protein of the food should bear to the carbohydrates and fat (nutritive ratio) has been a matter of considerable study and dispute. The International Congress of Nutrition[1] in 1900 discussed the matter and concluded that a relation of 1:6 to 1:7 was the most suitable. Lavalard[1] states, as a result of his experiments, that 1:6 to 1:9 are permissible and satisfactory. Kellner[2] states that for horses doing work at a walk a ratio of 1:10 is allowable, but that for hard work, and especially work done at a trot, a ratio of 1:7 is preferable, because in such cases extra protein is needed to furnish maximum amounts of blood in order to carry the oxygen required for the rapid breaking down of the food material.

5. Experience has taught feeders, especially in European countries, that it is advisable to crush the coarse grains before feeding, and to cut the roughage and make a mixture of the two. The cut roughage aids in absorbing any moist feeds, particularly molasses, and also serves as a distributor of the heavy concentrates.

6. French investigators have recommended the substituting of corn, barley, rye, oil cakes, sugar and molasses for oats, and the reducing of the coarse fodders to a minimum, particularly for hard-worked horses, — as low in some cases as 6 pounds daily per 1,000 pounds live weight.

7. Cut straw has been highly recommended in place of hay because it is cheaper, is less likely to cause colic, contains less foreign material than hay, and serves as an excellent medium for the distribution of the grain.

8. A mixture which the French authority, Lavalard, recommends consists of 8 pounds of oats, 9 pounds of corn, 1 pound of beans, 5 pounds of molassine meal, and 7 pounds of chopped straw. This mixture contains, of digestible nutrients, 1.7 pounds protein, .47 pound fat, 11.52 pounds carbohydrates, 27.5 pounds total dry matter, and 27,712 calories of energy and is sufficient for hard-worked horses of 1,100 pounds weight.

9. For roughage the coarser hays, including alfalfa and clover, are recommended, also oat, wheat and barley straws.

10. Kellner recommends also as satisfactory concentrates, in addition to the cereals (excepting wheat), linseed, cocoanut and palm nut meal in amounts not exceeding 1 to 2 pounds daily. He states that corn, small amounts of brewers' grains, rice and linseed meals can be used in order to reduce the amount of oats to a minimum.

11. In the United States relatively large amounts of corn are fed, while on the Pacific coast barley of good quality predominates. In the semiarid regions Kaffir corn and alfalfa have been used satisfactorily, particularly the latter.

12. The amount of water required daily depends upon the size of the animal, the work performed, and the time of year. The time of watering — whether before or after feeding — is a matter of minor importance. Horses become accustomed to both methods, and care should be taken to avoid sudden changes from the accustomed method.

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[1] L'Alimentation du Cheval, pp. 100, 101

[2] Die Ernährung d. landw. Nützthiere, Sechste Auflage, p. 455.

13. Horses are, as a rule, of a nervous temperament, and it is advisable to avoid anything that will prove a source of irritation to the intestines, and that will induce extra water consumption. Inferior fodder, especially moldy stuff, should never be fed.

D. Books on Horse Nutrition.

The Nutrition of Farm Animals, Armsby. Chapter XIV. Published by the Macmillan Company, New York, 1917.

The Productive Feeding of Farm Animals, Woll. Chapter XXIV. Published by J. B. Lippincott Company, Philadelphia, 1915.

Productive Horse Husbandry, Gay. Published by J. B. Lippincott Company, Philadelphia, 1914.

Feeds and Feeding, Henry & Morrison. Chapters XVIII, XIX, XX. Published by the Henry & Morrison Company, Madison, Wis., 1915.

A Digest of Recent Experiments on Horse Feeding, Langworthy. United States Department of Agriculture, Office of Experiment Stations, Bulletin No. 125, 1903.

Die Ernährung d. Landw. Nützthiere, Kellner, Sixth Edition, Part III, Chapter V. Published by Paul Paray, Berlin, 1912.

Grundlagen f. d. rationelle Fütterung des Pferdes, Wolff. Published by Paul Paray, Berlin, 1886.

L'Alimentation du Cheval, Lavalard. Published at Librarie Agricole de la Maison Rustique, Paris, 1912.

Le Cheval, Lavalard. Published by Librarie De Firmin Didot et Cie, Paris, 1888.

Les Aliments du Cheval, Duchambre et Curot. Published by Asselin et Houzeau, Paris, 1903.

PART II.

FEEDING TRIALS WITH HORSES.

RESULTS AND SUGGESTIONS.

(*a*) *Alfalfa for Horses.*

1. On the basis of 1,000 pounds' live weight, a ration composed of 1.7 pounds of oats, 6.8 pounds of corn and 8.5 pounds of alfalfa hay did not prove sufficient for horses doing reasonably hard farm work (Kansas ration).

2. Fed such a ration the horses appeared quite restless and nervous, and lost in live weight, indicating insufficient food and possibly an unfavorable action of the alfalfa upon the nervous system.

3. An increase of 10 per cent. in the above ration checked the loss of live weight, but not the restless, hungry condition.

4. The substitution of a timothy hay mixture for a portion of the alfalfa seemed to check in a measure the restless condition of the horses.

5. During the fall months the same grain ration was maintained, but timothy hay was substituted for all of the alfalfa. The horses fully maintained their weights and appeared quieter than when the alfalfa ration was fed. This may have been due in part, at least, to the fact that less work was required daily than in the early part of the season.

6. A combination of one-fifth oats and four-fifths corn, together with a mixture of one-half alfalfa and one-half timothy, is likely to prove more satisfactory than a ration in which alfalfa constitutes the entire roughage.

7. A combination of one-third oats and two-thirds corn and timothy hay appears to be quite satisfactory, and furnishes sufficient protein for horses doing ordinary work. Only when quite hard work is required is it necessary to increase the protein by feeding alfalfa or a small amount of a protein concentrate. In such cases the roughage should be reduced and the amount of grain increased.

(*b*) *Brewers' Dried Grains for Horses.*

Brewers' grains, when prepared from perfectly fresh material, may constitute from 15 to 25 per cent. of the daily grain ration for horses, and may replace a like amount of oats.

(*c*) *Velvet Bean Feed for Horses.*

1. Velvet bean feed represents the ground bean and pods of a tropical legume.

2. At this station a ration composed of oats, corn, wheat bran and 20 per cent. velvet bean feed was fed to two farm horses for a period of three months, and gave quite satisfactory results.

3. While it would be possible to increase the amount of this feed in the mixture, it would hardly be advisable because the pods render the feed less digestible than corn.

4. Some lots have been found upon the market more or less moldy, due to imperfect drying. Such material is quite unfit for horses. Care should be taken to feed only well-dried, sweet material.

(*d*) *Linseed Meal for Horses.*

1. During a period of two months the horses received a ration of oats, corn and 7 per cent. linseed meal. They ate the mixture readily and appeared in excellent condition during the entire time.

2. It is preferable in feeding this material to have the other grains with which it is mixed at least coarsely ground, otherwise the linseed meal separates out and is not likely to be eaten as readily. The addition of 5 to 7 per cent. of linseed meal to the grain ration for hard-worked horses should prove very helpful.

(*e*) *Rations for Work Horses.*

The amount of roughage fed may vary between 1 and 1¼ pounds daily per 100 pounds' live weight. Alfalfa may constitute one-half of the roughage. The amount of grain to be fed will depend, naturally, upon the character and amount of the work performed. From 1 to 1.4 pounds daily per 100 pounds of live weight should prove sufficient under most conditions.

I.

100 pounds of oats.
400 pounds of corn.
½ hay and ½ alfalfa.

II.

100 pounds of oats.
200 pounds of corn.
Timothy or mixed hay.

III.

100 pounds of brewers' dried grains.
150 pounds of oats.
200 pounds of corn.
50 pounds of wheat bran.
Timothy or mixed hay.

IV.

125 pounds of brewers' dried grains.
100 pounds of oats.
225 pounds of corn.
50 pounds of wheat bran.
Timothy or mixed hay.

V.

100 pounds of velvet bean feed.
150 pounds of oats.
200 pounds of corn.
50 pounds of wheat bran.
Timothy or mixed hay.

VI.

100 pounds of oats.
180 pounds of corn.
20 pounds of linseed meal.
Timothy or mixed hay.

Hominy meal or crushed barley may be fed in place of one-half of the cracked or whole corn if desired. Molasses may constitute 10 per cent. of the grain mixture. It may be diluted somewhat with water and mixed with the grain. It aids in preventing colic. Inferior hay — weedy or moldy — and musty grain are to be avoided as causes of digestion disturbances.

A. Alfalfa for Horses.

The Kansas Experiment Station,[1] co-operating with the United States Department of Agriculture, conducted a series of experiments in the feeding of work horses, using the artillery horses at Fort Riley (937 in all), with an average weight of 1,165 pounds. The work performed was called rapid light draft, and consisted of marching and drilling, drawing heavy wagons and guns often at a trot or gallop. Among the many rations tried was one composed, on the basis of 1,000 pounds of live weight, of 6.8 pounds of corn, 1.7 pounds of oats and 8.5 pounds of alfalfa hay, which contained, according to calculations made by the experimenters, the following digestible nutrients: —

Kansas Ration.

Protein,	1.655
Carbohydrates,	8.720
Fat,	.408
Total (fat × 2.2),	11.270
Nutritive ratio,	1:5.800

The alfalfa experiment was conducted with 17 horses for one hundred and forty days, and during the test the horses showed an average gain of 25.6 pounds per head. It was stated that they showed no signs of shortness of wind, softness, lack of endurance, laxative effect or excessive urination. The amount of grain was reduced 19 per cent. and the amount of hay 30 per cent. from that consumed in a check ration of prairie hay and oats. The observers explain the satisfactory results on the ground that a small amount of alfalfa hay was fed with a relatively large amount of corn, a combination requiring a minimum amount of energy for its digestion.

The 1,000-pound horse, working eight hours daily, requires, according to Armsby *et als.*,[2] 2 pounds of digestible crude protein and 18.2 therms of net energy. The horses in the Kansas alfalfa ration received 1.67 pounds of digestible crude protein and 13.41 therms of net energy.

On the basis of digestible matter the following comparison can be made of nutrients required per 1,000 pounds' live weight for medium to hard work: —

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[1] Bul. No. 186.

[2] The Nutrition of Farm Animals, p. 714.

AUTHORITY.	Protein.	Carbo-hydrates.	Fat.	Total (Fat × 2.2).	Nutritive Ratio.
Alfalfa ration,	1.655	8.721	.408	11.26	1 : 5.8
Lavalard's standard for comparison,	1.330	11.170	–	12.50	1 : 8.3
Grandeau's standard for comparison,	1.920	10.920	.400	12.83	1 : 5.7
Kellner's standard for comparison,[1]	1.600	12.500	.600	14.20	1 : 7.9
Kellner's standard for comparison,[2]	2.170	13.700	.800	15.87	1 : 6.3

[1] Medium work.

[2] Hard work.

It appears that while the Kansas ration contained ample protein on the basis of accepted standards, it was deficient in total digestible nutrients and in therms of net energy. It seems to have been successful for the army horses doing the regular work required of them, but it is doubtful to the writer if it would prove sufficient in amount for horses doing medium to hard farm work.

Experimental.

In order to test the efficiency of this ration, two young western horses designated as Tom and Joe, which were purchased the winter previous, and which had been doing farm work during the spring and summer, were placed, Sept. 11, 1916, on the Kansas ration. Tom received 2½ pounds of oats, 9½ pounds of cracked corn and 12 pounds of alfalfa hay, and Joe received 2¼ pounds of oats, 9 pounds of cracked corn and 11 pounds of alfalfa. The hay fed for the first three weeks was grown upon the station grounds, was fine, but mixed with more or less foreign grasses. On October 6 it was replaced with a coarser but better grade, this second cutting said to have been grown in Michigan. The ration was fed in three portions daily, and the horses weighed on each Monday morning before feeding and watering.

Weights.

	Tom.	Joe.
September 17,	1,415	1,305
September 24,	1,415	1,295
October 1,	1,415	1,290
October 8,	1,425	1,285
October 15,	1,405	1,285
October 22,	1,410	1,285
October 29,	1,400	1,280
November 6,	1,415	1,310
November 13,	1,425	1,335

Although, as has been previously shown, this ration was deficient in both total digestible nutrients and therms of net energy, the horses held their weights, due in all probability to the light work performed during the autumn months. They appeared hungry and very restless, the latter condition, in the opinion of the writer, being in part at least, a result of the influence of the alfalfa upon the nervous system.

Beginning in the spring of 1917 the two horses which had been used on digestion experiments the preceding winter were worked on the farm and fed the Kansas alfalfa ration. On the basis of live weight Tom received daily 2¾ pounds of oats, 10½ pounds of cracked corn and 12 pounds of alfalfa, and Joe received 2½ pounds of oats, 9 pounds, 14 ounces of corn and 11 pounds of alfalfa.

Weights.

	Tom.	Joe.
April 23,	1,390	1,310
April 30,	1,390	1,280
May 7,	1,390	1,290
May 14,	1,400	1,295
May 21,	1,380	1,285
May 28,	1,370	1,275
June 4,	1,370	1,260

It was necessary to work them lightly during the first month. As the work was increased in amount they began to show a gradual loss in weight and to appear very nervous and hungry. Because of such conditions, and of the additional spring work required of them, the ration was increased 10 per cent. June 4, Tom receiving 13.2 pounds of alfalfa, 3 pounds of oats and 11.5 pounds of corn, and Joe receiving 12.1 pounds of alfalfa, 2.7 pound of oats and 10.9 pounds of corn.

Weights.

	Tom.	Joe.
June 11,	1,390	1,275
June 18,	1,400	1,280
June 25,	1,400	1,275
July 2,	1,410	1,270
July 9,	1,420	1,270
July 16,	1,430	1,300

These rations contained the following pounds of digestible nutrients and therms of net energy: —

	Protein.	Carbo-hydrates.	Fat.	Total (Fat × 2.2).	Therms.	
					Fed.	Required.
Tom,	2.56	14.02	.59	17.80	22.21	25.48
Joe,	2.37	13.05	.54	16.60	20.72	23.66
Grandeau standard,	2.69	–	–	17.96	–	–

In so far as weights and digestible nutrients were concerned, the horses appeared to have received sufficient food for the work they were doing. The therms fed fell below the standard theoretically required, which leads one to question whether this standard is not too high. The horses still appeared rather restless and hungry, although they performed their daily task in a more satisfactory way. Beginning July 16 the ration was modified by reducing the amount of alfalfa fed daily to each horse to 10 pounds, and adding 6 pounds of timothy mixture to Tom's ration and 5 pounds to Joe's ration, the grain remaining as in the ration preceding. The object of the change was to attempt to reduce the restless action manifested by the horses, which in a measure was successful, and their weights were maintained.

Weights.

	Tom.	Joe.
July 16,	1,430	1,300
July 23,	1,430	1,300
July 30,	1,415	1,270
August 6,	1,410	1,270
August 13,	1,410	1,280
August 20,	1,420	1,300
August 27,	1,410	1,270
September 3,	1,410	1,300

Beginning September 4, hay was substituted for the entire amount of alfalfa, the grain ration remaining constant. The calculated digestible nutrients and weights of the horses follow: —

	Protein.	Fiber.	Extract Matter.	Fat.	Total (Fat × 2.2).	Nutritive Ratio.	Therms.	
							Fed.	Required.
Tom,	1.87	2.85	13.36	.52	19.22	1 : 9.3	20.00	25.48
Joe,	1.70	2.66	12.55	.47	17.94	1 : 9.5	18.80	23.66
Grandeau's standard (1,400-pound horse).	2.69	–	–	–	17.96	–	–	–
Lavalard's standard (1,400-pound horse).	1.86	–	–	–	17.20	–	–	–

Weights.

	Tom.	Joe.
September 10,	1,410	1,300
September 17,	1,445	1,310
September 24,	1,390	1,275
October 1,	1,405	1,290
October 8,	1,395	1,300
October 15,	1,420	1,330
October 22,	1,400	1,320
October 29,	1,410	1,295

The weights were well maintained, indicating that for the work performed sufficient nutriment was being supplied. The work was rather irregular during this period, and may be considered as light.

The combination of hay, corn and oats evidently was sufficient in total digestible nutrients, but rather deficient in protein, according to Grandeau, for horses doing moderate work. The therms of energy were noticeably below the standard. The ration conformed more closely to that set by Lavalard, who accepts one with less protein and a wider nutritive ratio than other investigators. It is well known that horses keep in good condition and do satisfactory work on rations composed of hay, corn and oats. It seems probable, therefore, that only in case of quite hard work is it desirable to increase the protein requirement above the amount furnished by such a combination. Less corn and more oats, *i.e.*, rather more protein and less starch, or a somewhat narrower ration, is desirable in the warm summer months.

While recognizing the large number of horses in the Kansas experiment and the satisfactory results secured, on the basis of our own observations and the accepted feeding standards it seems to the writer that the amounts of the several feeds are not likely to be sufficient, nor the combination particularly satisfactory, for most work horses. It is believed that for each 100 pounds of live weight a pound of roughage is a reasonable allowance, and that one-half of this roughage may consist to good advantage of alfalfa, and the balance of a timothy mixture.

B. Brewers' Dried Grains for Horses.

Brewers' dried grains, the residue of the beer breweries, contain from 20 to 28 per cent. of protein, 13 to 17 per cent. of fiber, 5 to 7 per cent. of fat, and from 40 to 46 per cent. of extract matter. They contain more protein, fat and fibre than oats, some 14 to 20 per cent. less extract matter, and possess about 15 per cent. less net energy value. Voorhees[1] of the New Jersey station, as a result of feeding trials, stated, "That on the whole a pound of dried brewers' grains was quite as useful as a pound of oats in a ration for work horses." Foreign investigators have stated that they can replace one-half of the oat ration. In New England, while they have been used more or less, one fails to learn of their general employment as a part of the daily ration. If used especially for horses, it is quite important that they be dried before being allowed to sour or decompose.

This station has fed them as a component of horse rations with satisfactory results. The same two horses that were used in the alfalfa experiment were employed. They did moderate farm work which consisted principally of plowing, harrowing and teaming.

Ration I.

5 pounds of ground oats.
3 pounds of brewers' grains.
8 pounds of cracked corn.
2 pounds of wheat bran.
15 pounds of timothy mixture.

The ration contained the following digestible nutrients in pounds and net energy value in therms on the basis of 1,000 pounds of live weight: —

Authority.	Protein.	Total (Fat × 2.2).	Nutritive Ratio.	Therms.
Brewers' dried grain ration,	1.76	12.00	1 : 5.9	15.1
Kellner's standard (moderate work),	1.40	12.62	1 : 8.0	–
Lavalard's standard (moderate work),	1.33	12.50	1 : 8.3	–
Grandeau's standard (moderate work),	1.92	12.83	1 : 7.9	–

The above comparisons indicate that the ration fed contained substantially sufficient digestible protein and total nutrients. The horses were weighed weekly in the morning, before feeding and watering.

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[1] Bul. No. 92, N. J. Agr. Exp. Sta.

Weights.

	Tom.	Joe.
May 22,	1,400	1,240
May 29,	1,400	1,280
June 5,	1,400	1,275
June 12,	1,425	1,285
June 19,	1,425	1,290

It seemed evident that for the work performed the horses were receiving sufficient nutrients to keep them in normal condition, although they did not materially add to their weight.

Ration II.

On June 19 the ration was modified slightly by replacing 2 pounds of the oats with 2 pounds of the brewers' grains, thus increasing the protein slightly, while the total nutrients received were nearly the same.

Weights.

	Tom.	Joe.
June 26,	1,420	1,260
July 3,	1,415	1,250
July 10,	1,420	1,240
July 17,	1,400	1,240

During this period there seemed to be a slight loss in weight. Whether this was due to the warm weather or to the modification of the ration is not clear.

Ration III.

On July 17 the horses were put back on to Ration I and continued until August 14.

Weights.

	Tom.	Joe.
July 24,	1,420	1,300
July 31,	1,415	1,270
August 7,	1,410	1,285
August 14,	1,405	1,270

Slight shrinkages in weight were noted.

Ration IV.

On August 14, because the horses were doing somewhat less work, Ration I was reduced 1 pound each of oats and cracked corn.

Weights.

	Tom.	Joe.
August 21,	1,440	1,305
August 28,	1,435	1,310
September 4,	1,425	1,265
September 11,	1,435	1,295

It will be seen that the rations fed the two horses from about the middle of May until September 11 contained from 3 to 5 pounds of the brewers' grains out of a total of 18 pounds of grain (or from 17 to 28 per cent.). At the beginning the horses weighed 1,400 and 1,240 pounds, respectively, and at the close, 1,435 and 1,295 pounds. During this time variations in weight were noted, due perhaps partly to increase or decrease in work, and partly to weather conditions. The horses kept in uniformly good condition throughout the season, indicating that the brewers' grains in the amounts fed exerted no adverse effect upon them.

The writer is inclined to favor Rations I and II as satisfactory combinations, especially if the brewers' grains can be purchased for less than the oats. It is not advisable under most conditions to include too large an amount of brewers' grains in the ration, for the reason that they will furnish too much protein and not sufficient digestible matter.

C. Velvet Bean Feed for Horses.

The velvet bean, of which there are many varieties, is a tropical legume and is grown largely in Florida, Alabama and Mississippi. It needs a long season for its maturity and is rarely grown north of Savannah. It is a rank grower, the vines trailing on the ground to a length of from 15 to 75 feet; they are difficult to secure for hay, and have been used largely for grazing. It is now more common to pick the best of the beans and use them without hulling for cattle, or hulled as a food for pigs. Machinery has been devised for drying and grinding the unhulled beans, thus producing the velvet bean feed, and it is said that the industry is increasing rapidly.

Analysis and Digestibility of Velvet Bean Feed (Bean and Hulls).

	Composition.	Percentage Digestible.	Pounds Digestible in 2,000.
Water,	12.00	–	–
Ash,	5.11	32	32.7
Protein,	16.80	75	252.0
Fiber,	12.85	63	161.9
Extract matter,	49.00	85	833.0
Fat,	4.24	81	68.7
Total,	100.00	–	1,348.3

In chemical composition the feed does not vary greatly from wheat bran, except that it has rather more fiber derived from the bean pods. It contains about 175 pounds more digestible organic nutrients per ton than bran, and should have a somewhat greater feeding value.

The present spring the experiment station fed it as a component of a ration to the two station horses which were being used on general farm work and which had been employed in digestion experiments the previous winter.

Ration I.

Ration I, which we began feeding in May, was composed of a mixture of —

	Pounds.
Oats,	100
Corn,	160
Velvet bean feed,	40
Wheat bran,	40

The velvet bean feed constituted 11.7 per cent. of the ration. The horses ate the ration freely, Tom receiving 18 pounds and Joe 17 pounds daily, in addition to 15 pounds of hay.

Ration II.

On June 8 the ration was modified by increasing the velvet bean feed to 60 pounds and decreasing the corn to 140 pounds in the mixture.

The velvet bean constituted nearly 18 per cent. of the mixture, and each horse received a little over 3 pounds a day. The weights of the horses follow: —

	Tom.	Joe.
June 3,	1,395	1,280
June 10,	1,345	1,245
June 17,	1,370	1,265
June 24,	1,400	1,285

During this period these horses were working eight to nine hours daily for $5\frac{1}{2}$ days each week, doing plowing, harrowing and similar farm work. They maintained their live weight, but were not in as good flesh as was desired.

Ration III.

On June 24 the hay was increased to 18 pounds daily, and so continued until July 15, for the reason that they acted rather hungry, and it was thought a little more bulk would render them more contented.

Weights.

	Tom.	Joe.
July 1,	1,370	1,270
July 8,	1,395	1,300
July 15,	1,400	1,300

The work during the above time was of about the same character, but on the whole not as difficult as during June. The live weight appeared to be maintained, but apparently did not increase.

Ration IV.

On July 15 the grain mixture was increased to 20 pounds for Tom and 19 pounds for Joe, in addition to the 18 pounds of hay, and so maintained until September 1.

Weights.

	Tom.	Joe.
July 22,	1,400	1,300
July 29,	1,390	1,290
August 5,	–	–
August 12,	1,410	1,320
August 19,	1,395	1,320
August 26,	1,400	1,320
September 2,	1,405	1,325

During the above period Tom appeared stationary and Joe increased about 25 pounds in weight. Tom is a long-bodied, long-legged horse and not as compact of build as is Joe. In spite of the fact that the live weight was not substantially increased, the horses appeared in better condition than in the early summer. The horses were quite fully employed during August in harrowing, plowing and drawing manure.

The estimated pounds of nutrients and therms of energy contained in the daily ration on the basis of 1,400 pounds live weight follow: —

	Protein.	Total (Fat × 2.2).	Nutritive Ratio.	Therms fed.	Therms needed (Armsby).
Feeds: —					
15 pounds hay + 18 pounds grain equals	2.43	20.37	1 : 7.4	20.40	25.5
18 pounds hay + 20 pounds grain equals	2.76	23.37	1 : 7.4	23.00	25.5
Authority: —					
Kellner's standard for comparison (moderate work).	2.00	17.70	1 : 8.0	-	-
Kellner's standard for comparison (hard work).	2.80	24.50	1 : 7.7	-	-
Lavalard's standard for comparison (moderate work).	1.86	18.10	1 : 8.3	-	-
Grandeau's standard for comparison (moderate work).	2.20	17.96	1 : 7.9	-	-

It is believed that 15 pounds of hay and 18 pounds of grain, of which velvet bean feed constituted some 3 pounds, were sufficient for the work the horses did from week to week. It is possible that during a few days, or for a week at a time, the nutrients were not sufficient. The other ration, consisting of 18 pounds of hay and 20 pounds of grain, probably was more than was needed.

The horses ate the ration, of which velvet bean feed comprised some 18 per cent., continuously for over three months, and the results were in every way satisfactory.

D. Linseed Meal as a Grain Supplement for Horses.

Beginning September 1 the two horses Tom and Joe were fed a grain ration composed by weight of 100 pounds of whole oats, 160 pounds of whole corn, and 30 pounds of old process linseed meal. Tom received daily 20 pounds of the mixture and Joe 19 pounds, in addition to 18 pounds of hay. This ration was continued until September 28, when it was slightly modified by decreasing the linseed meal to 20 pounds in the mixture, or about 7 per cent. The reason for the reduction was that the linseed did not mix evenly with the corn and oats, owing to the fact that they were not ground or crushed; hence considerable would separate out and the horses were inclined to leave a little. Horses do not seem to care particularly for the linseed if fed unmixed, but will eat a reasonable amount readily if constituting a part of a mixture. This ration was continued until November 11. The horses did regular farm work during this period, but did not average as many hours daily as earlier in the season, and the work would be considered only moderate.

Weights.

	Tom.	Joe.
September 2,	1,405	1,325
September 9,	1,395	1,315
September 16,	1,405	1,330
September 23,	1,435	1,345
September 30,	1,445	1,350
October 7,	1,450	1,370
October 14,	1,440	1,340
October 21,	1,425	1,340
October 28,	1,415	1,340
November 4,	1,410	1,350
November 11,	1,425	1,360

Digestible Nutrients in Ration (Pounds).

	Protein.	Total (Fat × 2.2).	Nutritive Ratio.
18 pounds hay + 20 pounds grain equals	3.11	24.04	1 : 6.7
Kellner's standard (hard work),	2.80	24.50	1 : 7.7

On the basis of the calculated digestible nutrients it is evident that the horses were receiving all the food necessary for eight hours of hard work daily. The work actually performed could only be called moderate, which explains to an extent the gain in live weight. It is believed that the addition of 5 to 10 per cent. of linseed meal to a grain ration composed of one or more cereals will prove helpful, especially to hard-worked horses, and will be eaten without trouble.

BULLETIN No. 189 MARCH, 1919

MASSACHUSETTS
AGRICULTURAL EXPERIMENT STATION

The European Corn Borer and its Control

By STUART C. VINAL and D. J. CAFFREY

Requests for bulletins should be addressed to the
Agricultural Experiment Station,
Amherst, Mass.

Publication of this Document
approved by the
Supervisor of Administration.

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BULLETIN No. 189.

DEPARTMENT OF ENTOMOLOGY.

THE EUROPEAN CORN BORER AND ITS CONTROL.

BY STUART C. VINAL AND D. J. CAFFREY.

FOREWORD.

During 1918 the Massachusetts Agricultural Experiment Station and the Bureau of Entomology of the United States Department of Agriculture worked on the European corn borer under a co-operative agreement by which the station was to make a study of the life history, food plants, methods of distribution and methods of control of the insect, while the Bureau was to determine its distribution, develop control measures and prevent its further spread.

Mr. Stuart C. Vinal, assistant entomologist of the experiment station, was assigned to this work on the station side, and located in Arlington. He worked day and night on the subject and accomplished an enormous amount, but with such disregard for his health that when attacked by influenza he was unable to resist it and died Sept. 27, 1918.

The person best fitted to take up and bring together for publication the information gathered by Mr. Vinal was Mr. D. J. Caffrey, who had been in charge of the Bureau side of the work, and who had been in close touch with Mr. Vinal's investigations throughout the year, and he therefore took the material left by Mr. Vinal and has brought it together and put it in shape for publication. Fortunately, most of it was already well worked out, but providing the data obtained by the United States government as its share of the work, and the form and arrangement of the whole bulletin have been Mr. Caffrey's contribution. The line drawings have been prepared by the writer of this foreword, from sketches made by Mr. R. E. Snodgrass of the United States Bureau of Entomology.

H. T. Fernald.

INTRODUCTION.

Practically all insect pests of foreign origin found in the United States have reached our seaports through the agency of commerce. The great variety of living plants, as well as raw materials for use in manufacturing enterprises and the miscellaneous freight and personal effects that are daily received on our shores from all parts of the world, provide an ample opportunity for the entrance of almost any destructive pest. Many of these insect immigrants, on finding favorable climatic and food plant conditions, become permanently established, and in the course of time spread from their point of origin and become of more economic importance each year, unless checked by artificial agencies.

The danger existing from these involuntary importations of destructive insect pests is still further increased by the fact that in most instances their natural enemies are not imported with them. Under these circumstances the pest is enabled to extend its activities without being subject to the natural handicaps imposed by nature. This results in a more rapid multiplication and a greater degree of destructiveness than exists in the original habitat of the insect.

Such, in brief, is the history of many of our most important and generally distributed insect pests of to-day.

To the long list of foreign pests now found in the United States must be added the European corn borer, or corn pyralid, *Pyrausta nubilalis* Hübner, which has recently become established in the eastern part of Massachusetts.

The caterpillar of this insect has long been recorded in Europe and Asia as one of the most serious insect enemies of corn, hemp, millet, hops and other crops. Corn and hop plants are very severely damaged by this pest, 50 per cent of these crops often being destroyed in some sections of Central Europe.

As a result of studies made on the habits and destructive powers of the European corn borer throughout the infested portion of Massachusetts during the seasons of 1917 and 1918, it is evident that this species is without doubt the most dangerous and destructive insect enemy of the corn crop that has yet been introduced into the United States. As corn is one of the bulwarks of American agriculture, and has within the past few years become our most valuable crop from a monetary standpoint, it will be recognized that the problem of controlling this insect which threatens to destroy a large per cent of the crop each year is not confined to Massachusetts, but is a problem of national importance, which must be acted upon promptly and thoroughly to the end that the insect may be at least confined to its present area of distribution, if ultimate extermination is found to be impossible.

If this insect is allowed to extend its area of distribution and reach the corn belt of the middle western States, it will be a national calamity. Although Massachusetts is universally considered to be a manufacturing

State, it should be stated that during 1917 a total of 2,806,000 bushels of field corn were grown in the State which were worth $6,033,000 according to the prices prevailing the 1st of the following December. This is in addition to the value of the sweet corn, fodder corn and popcorn produced in the State. Aside from the national importance of restricting the spread of this dangerous insect, the State of Massachusetts should take all measures to protect the revenue obtained from its corn crop.

There are several other species of destructive corn borers known to attack corn in the United States, the most important of which are the larger cornstalk borer, *Diatræa zeacolella* Dyar, and the lesser cornstalk borer, *Elasmopalpus lignosellus* Zeller. These two species occur in the South, and even to some extent in the northern States, but have never become permanently established in Massachusetts or any other State with a similar climate. They are doubtless unable to withstand the severe winter conditions, and this characteristic has the effect of greatly limiting their range of distribution. The European corn borer, however, is not limited in its range by ordinary climatic conditions, judging from its range of distribution in the Old World, and from its behavior to date in the infested area of Massachusetts. The species would thus be able to adapt itself to all parts of Massachusetts and ultimately to the entire country.

In Massachusetts the only native stalk borer attacking corn is *Papaipema nitela* Gn., which more frequently infests the stalks of potatoes, tomatoes and numerous common weeds. This insect, however, does not normally occur in sufficient numbers to cause serious loss. During the past two seasons, however, it has been rather more abundant than usual and because of the fact that its injuries to corn superficially resemble those caused by the European corn borer, much of the damage really caused by the latter has been attributed to the native stalk borer.

SYNONOMY.

The species was first described and figured by Jacob Hübner (2) in 1796. He described the male and female as separate species, — the male as *Pyralis nubilalis*, and the female as *Pyralis silacealis*. Owing to this fact the synonomy of the species in Europe is somewhat confusing.

Haworth (3) in 1811 refers to the species as *Pyralis glabralis*.

Treitschke (4) in 1829, and Duponchel (5) in 1831, adopted the name *Pyralis silacealis* Hübn., although recognizing that the *Pyralis nubilalis* of Hübner was the male of *Pyralis silacealis* Hübn.

Guenée (7) in 1854 accepts the species as being identical with the *Botys cupulinalis* illustrated in the Icones Insectorum of Clerck (1) in 1759. A study of the figure referred to in Clerck's work, however, convinced later workers that it could not be the same insect. Nevertheless, this error by Guenée led to the acceptance of *Botys* as the generic name by several succeeding workers.

During the same year Guenée (8) gave the name *Botys zealis* to a species from the East Indies very close to *Botys eupulinalis*. After the description he adds this note: "It may be simply a variation of our *eupulinalis*, or, rather, this latter may have become acclimated among us with the cultivation of maize, and may be of exotic origin." In the present state of our knowledge the first theory seems to be the most probable.

Lederer (9) in 1863 retains the species in the genus *Botys*, where it had been placed through the faulty conception of Clerck's figure, by Guenée, as previously mentioned. Lederer, however, accepts the figure of Hübner's *nubilalis* as truly representing the species, and refers to it as *Botys nubilalis*. This name is accepted by Staudinger and Wocke (10) in 1871.

Moore (12) in 1888 refers to the species as *Hapalia kasmirica*. He is followed by Butler (13) as late as 1889, who designates the species as *Hapalia eupulina* (*non* Clerck).

Meyrick (14) in 1895 removed the species to the genus *Pyrausta*, and retained the *nubilalis* of Hübner, in which he has since been followed by Hampson (15), and by Staudinger and Rebel (17) in 1901.

We may therefore accept the species as *Pyrausta nubilalis* Hübn.

COMMON NAMES APPLIED TO SPECIES.

In Europe several different common names are applied to the species under consideration. The names most frequently used are the "corn pyralid;" "maize pyralid;" "pyralid of the maize;" "maize botys;" "botys;" "millet botys;" and "der Maiszunsler."

In the literature concerning the insect which has been published in the United States since its discovery, the species has been referred to as the European corn borer and the European cornstalk borer.

The former name undoubtedly is more appropriate for the insect, as the larvæ attack all parts of the corn plant except the fibrous roots, and do not confine their operations to the stalk as the name cornstalk borer would imply. Although many plants are attacked by the insect, corn is its favorite host, and is injured to a greater extent than any other commercial crop attacked by it. The name European is adopted to indicate its foreign origin, although the species is indigenous to other parts of the world. Taking all facts into consideration, it is believed that the name European corn borer is the most appropriate common name for the insect, and as such it will be considered in this bulletin.

FOREIGN HISTORY.

Foreign literature contains a large number of references to the serious damage caused by *P. nubilalis*, a loss of 50 per cent of the crops attacked being reported by some writers. There is, however, a decided lack of literature dealing with its biology and control. The only exceptions are the brief and incomplete articles by Robin and Laboulbène (11) in 1884, and of Jablonowski (16) in 1899. Robin and Laboulbéne detail the habits of the larvæ and the character of their damage to corn, hemp, hops and other food plants. The authors give an account of the severe damage which resulted from the attacks of this insect on corn, hemp and hops in the Department of the Aisne (France) during 1878 and 1879, as well as short extracts from the writings of other European authors mentioning the activities of this insect in various food plants. The absence of parasites is noted, and brief descriptions are given of the larva, pupa and adult. The authors recommend the burning of plants containing the overwintering larvæ, during the fall or early winter, as the most effective means of control.

Jablonowski records a very severe outbreak of *P. nubilalis* which destroyed a fourth part of the corn crop in Hungary during 1898. This damage was especially pronounced in the large plains of Hungary, which are very fertile. The author describes the character of the damage caused by the larva to corn, millet, hemp, hops and various minor food plants. The adult is described and figured very accurately; its habits of flight are detailed, and also the oviposition habits of the female. Mention is made of a single parasitic fly (*Ceromasia interrupta* Rdi.) which the author bred from the larva. Reference is also made to Kollar (6), who in 1837 recorded that some Ichneumonidæ had been bred from the species. For control measures Jablonowski recommends that early in the season, when most of the larvæ are confined to the terminal nodes of the plant, these upper portions be cut off and thrown into a water barrel, to be subsequently treated with hot water or fluid manure. This procedure can be repeated at short intervals because the treatment will not curtail the harvest. After harvest the infested plants should be pulled up by the roots and burned. In cases where the upper parts of infested plants are harvested the remaining stubble should be lightly plowed up, collected with a rake and burned. The author mentions the fact that the plowing under of infested material does not injure the contained larvæ. He also states that after shelling the corn the cobs should be used as fuel during the winter. The burning of all wild grasses that may serve as host plants for the overwintering larvæ is another general recommendation. These methods were found to be attended with considerable labor and expense, but were very effective in controlling the pest in Hungary during the outbreak of 1898.

HISTORY IN UNITED STATES (MASSACHUSETTS).

Discovery of the Insect.

During the summer of 1917 the senior author found many sweet corn fields in the vicinity of Boston, Mass., which were being very severely injured by light-colored larvæ which tunneled in the stalk and later attacked the ears.

Further investigation disclosed the fact that the identity of these depredating larvæ was unknown to the entomologists of that section where the insect had been found. This aroused the interest of the senior author, who had early recognized the serious nature of the pest. He accordingly collected pupæ from infested cornstalks in the field during the month of July, 1917, from which the adults emerged early in August.

Identifying the Species.

To secure the identification of the species concerned, Dr. C. H. Fernald's extensive collection of both native and exotic moths was available at Amherst, Mass. An examination of his European collection revealed specimens of both male and female Pyralid moths, identical with those reared from the infested cornstalks in eastern Massachusetts. These European specimens had been determined by Mr. E. L. Ragonot, a French lepidopterist, as *Pyrausta nubilalis* Hübner.

Specimens of the moths reared in Massachusetts were also submitted to Dr. H. G. Dyar of the United States National Museum at Washington, D. C., who gave the same identification, stating that it was a common and very destructive pest of various wild and cultivated plants in the Old World.

A Previous Record in Massachusetts.

Prior to 1917 this insect had never been reported as occurring in the United States, although the following supplementary facts should be recorded. During August, 1916, specimens of dahlia stems infested by lepidopterous larvæ were sent to the Massachusetts Agricultural Experiment Station from three localities near Boston, Mass. (Medford, Everett and Lynn). Adults were bred from this material, but their identity was not discovered nor their significance realized at the time. Later, however, the senior author determined these adults as being identical with the *P. nubilalis* bred from corn in 1917. Thus *P. nubilalis* was first bred in the United States in 1916, although its identity was not known until adults were bred from corn in 1917.

Preliminary Investigations.

As soon as this pest was found to be of foreign origin, and its potential menace to American agriculture realized, its presence became of more than local importance, and a survey was made in eastern Massachusetts during the latter part of September, 1917, to roughly determine its distribution and any other pertinent facts bearing on the insect, and the results of this preliminary survey were published by the senior author (18) in December, 1917. At this time it was found that the insect had established itself in an area covering approximately 100 square miles, immediately north and northwest of Boston, Mass., and that the towns at the mouth of the Mystic River were more generally infested than the others. In this section are several cordage factories which import hemp

(*Cannabis sativa*) from Europe. This fact, together with the knowledge that hemp is one of the favorite food plants of *P. nubilalis* in Europe, at once suggested the possibility that this insect may have reached our shores through this medium. Early sweet corn grown in market gardens 10 to 12 miles inland had been seriously attacked by this pest for the past three or four years, and from this it is inferred that the species was imported about 1910, although this date is a mere conjecture. At this time (1917) sweet corn was found to be the only valuable commercial crop attacked by *P. nubilalis*, the early crop being damaged to the extent of 10 to 20 per cent, while the loss to late plantings ranged as high as 75 to 80 per cent. Several weeds and grasses were also noted as food plants of *P. nubilalis*. Observations made on the feeding habits of the species in the infested fields confirmed the original belief that the insect under consideration was possessed of characteristics that would render it a serious menace to the corn crop, and that it would be a very difficult pest to control. Burning, burying or feeding the plants containing overwintering larvæ were methods suggested for the control of the insect. It was pointed out that measures for insuring or compelling satisfactory handling of all infested material were very necessary, and that though these results might possibly be obtained by local organizations of farmers and gardeners instituting vigorous action, it seemed probable that the matter must be taken in hand by the State or Federal authorities if the insect was to be brought under control and its further spread prevented.

Plans made for Further Investigations.

Accordingly, Dr. H. T. Fernald, head of the Department of Entomology at the Massachusetts Agricultural Experiment Station, notified officials of the Bureau of Entomology at Washington, D. C., of the presence of the European corn borer in Massachusetts, and reviewed the facts already known as to the dangers existing from the presence of this pest. Plans were immediately made for co-operation between the Massachusetts Agricultural Experiment Station and the Bureau of Entomology, in a further investigation of the insect, in order to determine its biology and methods of possible control. Special attention was to be given to the food plants and distribution of the insect in the United States, with a view to recommending quarantine measures that would prevent the spread of the pest through avenues of commerce.

Quarters were established at Arlington, Mass., in April, 1918, and the results of the investigations to Nov. 30, 1918, are presented in this bulletin.

Control Measures during Spring of 1918.

During the spring of 1918 a campaign was inaugurated by the Massachusetts State Board of Agriculture, which had for its object the burning of cornstalks and other infested plants within the infested towns. This work was under the direct supervision of Mr. Wilfrid Wheeler, Secretary of the Board of Agriculture, and Mr. R. H. Allen, State Nursery Inspector. The infested towns were placarded with warning notices illustrating the insect, and recommending the burning of all cornstalks remaining from the previous year. This was supplemented by a detailed survey in each of the infested towns and the burning of cornstalks in instances where the owners failed to comply with the recommendations. The States Relations Service of the United States Department of Agriculture, through the county agricultural advisers and other agents, aided in this campaign of publicity.

CONTROL MEASURES DURING AUTUMN OF 1918.

In October, 1918, an extensive campaign was begun for the eradication of all cornstalks, weeds and crop remnants of the current season which contained the corn borer larvæ. This was under a co-operative agreement between the Massachusetts Department of Agriculture and the Bureau of Entomology, Section of Cereal and Forage Insect Investigations. Crews of men were placed in each of the infested towns, who, under the direction of competent foremen, burned infested material that had not been eliminated by property owners or their representatives. This was preceded by a similar campaign of publicity to that in force during the spring clean-up work, although on a larger scale. Town and State officials aided in this work in some instances by agreeing to destroy the infested plants growing on public property under their jurisdiction, but, owing to the early approach of severe winter weather, it is probable that the clean-up of infested plants will not be completed until the early spring of 1919.

QUARANTINE MEASURES ENACTED AND THEIR ORIGIN.

National Quarantine Measures.

In late July, 1918, it was found that many sweet corn ears exposed for sale in the wholesale markets at Boston were infested by larvæ and pupæ of the European corn borer. This circumstance at once suggested the possibility that these infested products might be shipped outside the area already infested by the insect and become sources of new infestations. As a result of reporting these facts to the Federal Horticultural Board a public hearing was held at Washington, D. C., Aug. 27, 1918, to consider a proposed quarantine of that portion of Massachusetts known to be infested by the European corn borer. At this time, however, quarantine action was deferred in order to await the results of the field conference scheduled to be held at Boston, Mass., Sept. 6, 1918, to consider ways and means of handling the problem.

This conference was attended by entomologists and agricultural authorities from all of the New England States, New York and New Jersey, and by officials of the Bureau of Entomology, the Massachusetts Market Gardeners' Association, and the Boston Produce and Fruit Exchange.

A field meeting was held in the morning, during which those attending the conference were taken to a badly infested sweet corn field at West Medford, and the injury of the insect to corn and other plants observed. In the afternoon the present status of the insect was discussed and suggestions made for its control or possible extermination. The consensus of opinion inclined very strongly to the belief that vigorous quarantine and control measures were necessary if the destructive insect was to be confined within its present limits. This course of action was favored jointly by the entomologists and by the representatives of the market gardeners and produce dealers present.

Accordingly, notice of quarantine No. 36, on account of the European Corn Borer, *Pyrausta nubilalis*, was issued by the secretary of agriculture through the Federal Horticultural Board, and became effective on and after Oct. 1, 1918. This quarantine order applied to the towns which were known to be infested by the insect, and prohibited the interstate movement, to points outside the quarantined area, of all corn fodder or cornstalks, whether used for packing or otherwise, green sweet corn, roasting ears, corn on the cob and corn cobs. No restrictions were placed on the interstate movement of any of the enumerated articles that had originated outside of the quarantined area and were shipped through it on a through bill of lading.

Further investigation will probably show the necessity for amending this quarantine order to include additional territory and other articles, plants or plant products liable to contain the insect.

State Quarantine Measures.

The Hon. Elbert S. Brigham, Commissioner of Agriculture of Vermont, learning of the dangers existing from the presence of the pest in Massachusetts, immediately sent his assistant, Mr. H. L. Bailey, to investigate the situation in the infested fields near Boston, and as a result the State of Vermont issued a quarantine notice, on account of the European corn borer, which became effective on and after Aug. 26, 1918. This quarantine prohibited the movement of all stalks or ears of the corn plant (*Zea mays*), either green or dried, from the State of Massachusetts into the State of Vermont, unless written permission be secured from the Commissioner of Agriculture of the State of Vermont. This restriction did not apply to ordinary commercial dried shelled corn used for feeding purposes, nor to any corn grown in other States and sent through Massachusetts in transit.

A similar quarantine to that by Vermont was established by the State of Connecticut, effective Sept. 20, 1918. Permits to ship corn on the ear, stover or other parts of the corn plant (except the shelled dry kernels, or cooked or preserved products, or corn grown in other States passing through the State of Massachusetts in transit) must first be obtained from the Director of the Connecticut Agricultural Experiment Station, and accompany each shipment.

GEOGRAPHICAL DISTRIBUTION.

IN THE OLD WORLD.

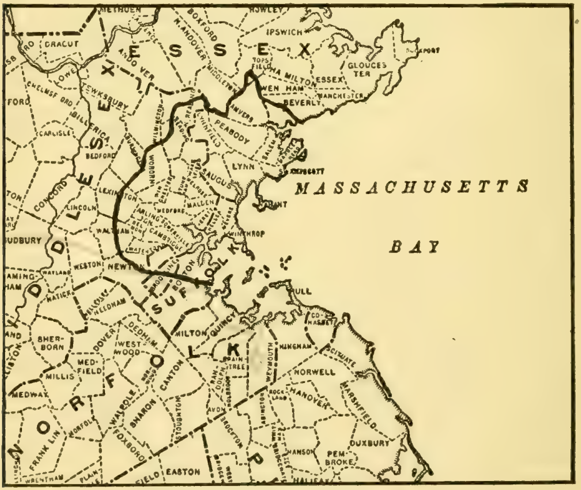
The European Corn Borer, or Corn Pyralid, *P. nubilalis* Hbn., is widely distributed in central and southern Europe, west central and northern Asia, China, Japan and the Philippine Archipelago.

Hübner, in his original record of the species, gave the habitat as Europe, western Asia, the Himalayas and Assam (British India).

A closely allied, if not, indeed, the same, species is reported from the East Indies (8).

IN THE UNITED STATES.

At the present time[1] the European corn borer, so far as is known, is found in the United States only in the counties of Suffolk, Middlesex, Essex and Norfolk, in the State of Massachusetts. Thirty-four towns are infested, comprising an area of approximately 320 square miles, or about three times the area believed to be infested after the discovery and preliminary survey of the situation in 1917. This area is located imme-


METHUEN
ROWLEY
IPSWICH
DRACUT
E S S E X
BOXFORD
TOPSFIELD
GLOUCESTER
ESSEX
WENHAM
MANCHESTER
BEVERLY
DANVERS
PEABODY
LOWELL
TEWKSBURY
CARLISLE
BEDFORD
LYNN
SAUGUS
M A S S A C H U S E T T S
B A Y
CONCORD
LEXINGTON
LINCOLN
MALDEN
WINTHROP
UDBURY
WESTON
NEWTON
WAYLAND
NATICK
NEEDHAM
HULL
MILTON
QUINCY
SHERBORN
WESTWOOD
HINGHAM
NORWELL
MEDFIELD
MILLIS
MEDWAY
CANTON
SHARON
WALPOLE
NORFOLK
FOXBORO
STOUGHTON
AVON
HANOVER
DUXBURY
PEMBROKE
EASTON
HALIFAX
S U F F O L K
N O R F O L K

Map showing area in Massachusetts infested by European corn borer, November, 1918. Heavy black line denotes limit of distribution.

---

[1] Nov. 30, 1918.

diately west and north of the city of Boston, Mass., and has as its limits the towns of Beverly, Danvers, Topsfield, Peabody, North Reading, Reading, Woburn, Lexington, Waltham, Newton, Brookline and Boston. (See map.) All the towns within these limits are infested to a greater or less degree.

Granting that the section near the mouth of the Mystic River was the original point of entrance, it will be noted that the European corn borer has shown a decided tendency to spread in a northerly and northeasterly direction. This characteristic has been exhibited by other insects introduced from Europe, notably the gypsy moth (*Porthetria dispar* L.) and the brown-tail moth (*Euproctis chrysorrhœa* L.). An examination of the meteorological records shows that during the periods when the adults of *P. nubilalis* are in flight, the prevailing winds are from the south and southwest. This may be the decisive factor in influencing the direction of the spread of *P. nubilalis*, as it is thought to be in the case of the other insects mentioned.

The area given above is believed to represent very accurately the limits of the district as yet invaded by the European corn borer. During the past season several men were engaged in determining these limits. In addition to this, the surrounding and contiguous territory in the States of Massachusetts, New Hampshire and Maine was examined for possible isolated infestations. Some other sections of these States were also examined because of the fact that their trade with infested sections near Boston might have led to the involuntary introduction of the pest in infested plant products. This was especially true of the summer hotel districts in Maine and New Hampshire, to which shipments of sweet corn were frequently made that had originated in the badly infested market-garden districts near Boston.

Territory examined in Massachusetts.

All of northeastern Massachusetts was examined to the New Hampshire line, and as far west as Tyngsborough, Westford, Acton, Sudbury, Wayland and Natick. On the south and east the territory was examined to Dover, Westwood, Canton, Randolph, Holbrook and Weymouth. Special attention was given the sections adjacent to the large cordage factories located at Andover and at Plymouth, with the idea that the pest may have been imported with hemp consigned to these factories. No infestation was found, however, outside the limits of the area previously designated.

Several reports were received during the season that the European corn borer was present in widely separated localities throughout the State. Care was taken to investigate all of these reports, but aside from those originating within the known area of infestation, it was found that insects other than *P. nubilalis* were responsible for the reported injury.

Territory examined in New Hampshire.

The entire southeastern section of New Hampshire, in addition to the summer hotel districts, was examined for evidences of the European corn borer by Mr. F. H. Gates of the Bureau of Entomology.

Particular attention was given the following localities, viz.: Portsmouth and surroundings, including New Castle; Greenland, Rye and Rye Beach; Hampton and Hampton Beach; Dover and vicinity; Rochester and vicinity; Farmington and vicinity; Concord and vicinity; Hookset; Manchester and vicinity, including Goffs Falls and Amoskeag; Derry and Londonderry; Nashua and vicinity; Pelham; Windham; Epping; and Thornton.

No evidences of the insect were found anywhere in New Hampshire.

Mr. W. A. Osgood, assistant to the deputy commissioner of agriculture of the State of New Hampshire, reports that, during October, 1918, he made a survey of the towns in the State bordering on Massachusetts, but did not find any indication of the European corn borer. Mr. Osgood had previously visited the infested fields near Boston, and had become familiar with the appearance of the pest.

Territory examined in Maine.

The following localities were examined in the State of Maine by Mr. R. H. Van Zwaluwenburg of the Bureau of Entomology for the possible presence of the European corn borer: Portland, — city and suburbs, including South Portland, Deering, Woodfords, Falmouth Foreside, Peak's Island and Great Diamond Island; Kennebunkport and Kennebunk Beach; Kittery; Wells Beach and village; Yarmouth; South Poland Springs and eastward to Danville Junction; Bath, — city and suburbs, including Woolwich; Rockland, — town and suburbs; Camden and Crescent Beach; Bar Harbor, — town and vicinity south to Newport Mountain and north to within a mile of Hull's Cove; Bangor, — city and suburbs, north to Mount Hope, south to Hampden Highlands and on east bank of the river south through Brewer to North Orrington; Augusta, — town and suburbs within a radius of 2 miles north and west, on east bank of river north to Riverside, east to Togus and south to opposite Hallowell; Hallowell; Gardiner; Lewiston, — city and suburbs; Auburn; Minot; and Mechanic Falls.

No evidences of the pest were found in the State of Maine.

During the progress of this survey Mr. Van Zwaluwenburg learned that considerable quantities of early sweet corn, originating in Massachusetts, had been shipped into Kennebunkport, Me., during the past few seasons. One retailer stated that he had recently received sweet corn, grown near Boston, that was infested with worms of some kind. The merchant had sold this shipment along with his other corn, however, and could give no testimony as to its ultimate disposal. A very careful examination of this section failed to reveal the presence of the European corn borer. This incident, however, demonstrates that the coastal region from Portland south to York, in the State of Maine, should be very carefully watched for the appearance of the species.

Mr. John A. Roberts, Commissioner of Agriculture of Maine, reported in August that his assistants had inspected sweet corn offered for sale in the stores at Augusta, Me., and were not able to find any evidence of the borer. Similar reports were received from Mr. Dudley of the same office, and from Mr. Batchelor of the Maine Agricultural Experiment Station. These gentlemen had previously visited the infested fields near Boston, and were familiar with the appearance of the insect.

Territory examined in Rhode Island and Connecticut.

Reports were received concerning the possible presence of the European corn borer in corn at Providence, R. I., but an investigation proved that the injury was caused by *Papaipema nitela* Gn.

A similar report, received from Putnam, Conn., was investigated and also proved erroneous.

FOOD PLANTS.

IN THE OLD WORLD.

The principal food plants of the European corn borer in the Old World are corn, hemp, hops and millet. Corn (both field corn and fodder corn) and hop plants are recorded as being more severely injured by the pest than any of the other commercial crops grown in Europe.

Foreign literature also contains references to a great variety of minor food plants, including heather (14); artemesia (13); nettles (13); oak-galls (15); kidney-bean pods (15); grapevines (18); thistle (18); giant weed, *Arundo donax* (12); pigweed, *Amaranthus retroflexus* (18); fuller's teazel, *Dipsacus fullonum* (18); virgin's bower, *Clematis vitalba* (18); and several species of wild grasses and weeds.

IN THE UNITED STATES (MASSACHUSETTS).

At the present time corn (sweet corn, field corn and fodder corn) is practically the only valuable commercial crop which is seriously attacked by the European corn borer in Massachusetts, although other commercial crops are attacked by the insect to some extent.

Corn is undoubtedly the favorite food plant of the pest. In the absence of corn, and in badly infested areas, the insect habitually attacks and enters a great variety of other wild and cultivated plants. Judging from observations made on the feeding habits of the species during the seasons of 1917 and 1918, it would not be surprising to find it present in almost any plant possessing a moderately soft, fleshy stem or stalk, or bearing a soft seed head during its early growth. Along the outer edge of the infested region, and in areas only recently invaded, the insect is almost always found exclusively in corn.

In badly infested fields the corn plants are frequently inhabited by so many feeding larvæ that all of the desirable plant tissue is quickly consumed, and under these circumstances the larvæ must leave their original host and enter other food plants growing in the vicinity in order to obtain food. Many of the eggs and smaller larvæ are sometimes dislodged from their original location on the corn plant and fall to the ground or upon other species of plants growing underneath, or between the rows of the corn, to subsequently infest these other plants. This characteristic often accounts for the great variety of infested plants found in the vicinity of badly infested corn fields.

The early season corn plants become dry and hard during July and August. Many of these plants contain belated *P. nubilalis* larvæ of the first generation, as well as small larvæ of the second. The comparatively soft tissue of late season plants growing in the vicinity often attracts the corn borer larvæ from their original food plant.

Plants other than corn, growing in areas planted to corn during the preceding year, frequently have eggs laid upon them by moths resulting from the overwintering larvæ in the crop remnants of the preceding year. In other instances the moths drift into areas where corn plants are absent, and deposit their eggs upon the most attractive food plant at hand. It is believed, however, that the moths prefer to deposit their eggs upon corn.

Another factor which is of interest in connection with selection of food plants is that the larvæ prefer large healthy plants, growing in well-fertilized land, to small plants of the same species, growing under less favorable conditions.

List of Food Plants.

The following table will show the list of food plants in which the European corn borer has been found in Massachusetts to date. This list has been compiled by dissecting the larva from each plant mentioned. Adults were reared in instances where the identity of the larva was in doubt.

The plants are arranged in order, with regard to their preference as food plants by the insect.

TABLE I. — *Food Plants of the European Corn Borer in Massachusetts.*

COMMON NAME.	Scientific Name.	Part of Plant attacked.
1. Sweet corn,	*Zea mays*,	All except root.
2. Field corn,	*Zea mays*,	All except root.
3. Fodder corn,	*Zea mays*,	All except root.
4. Barnyard grass,	*Echinochloa crus-galli* Beauv.,	All except root.
5. Pigweed (redroot),	*Amaranthus retroflexus* L.,	Stalk and seed head.
6. Dock,	*Rumex crispus* L. and *R. obtusifolia* L.	All except root.
7. Ragweed (hogweed),	*Ambrosia* spp.,	Stalk and seed head.
8. Lamb's-quarters,	*Chenopodium album* L.,	Stalk and seed head.
9. Dahlia,	– – –	Stalk and flower stems.
10. Foxtail,	*Setaria glauca* Beauv.,	Seed heads.
11. Lady's-thumb (smart weed),	*Polygonum persicaria* L.,	Stalk.
12. Burdock,	*Arctium minus* L.,	Stalk.
13. Horseweed,	*Erigeron canadensis* L.,	Stalk.
14. Beggar-ticks (bur marigold),	*Bidens frondosa* L.,	Stalk.
15. Purslane (pussley),	*Portulaca oleracea* L.,	Stalk.
16. Crab grass,	*Digitaria sanguinalis* Scop.,	Stalk.
17. Scouring rush,	*Equisetum* spp.,	Stalk.
18. Panic grass,	*Panicum dichotomiflorum* Michx,	Stalk.
19. Timothy,	*Phleum pratense* L.,	Seed head.
20. Goldenrod,	*Solidago* sp. L.,	Stalk.
21. Thistle,	*Cirsium* spp.,	Stalk.
22. Apple of Peru,	*Nicandra physaloides* L.,	Stalk.
23. Gladiolus,	– – –	Stalk.
24. Chrysanthemum,	– – –	Stalk.
25. Celery,	– – –	Outside stems.
26. Swiss chard,	– – –	Stalk and midrib of leaves.
27. Beans,	– – –	Pods, green beans and the vines.
28. Potatoes,	– – –	Vines.
29. Tomatoes,	– – –	Vines.
30. Beets,	– – –	Tops (stem and midrib of leaves).
31. Spinach,	– – –	Tops (stem and midrib of leaves).
32. Oats,	– – –	Stalks.
33. Turnips,	– – –	Tops (feeding on exterior of leaf stems).

Emphasis should be placed upon the fact that the great variety of food plants attacked will undoubtedly prove a serious complication in the problem of controlling the insect.

Several of these food plants or their products, notably sweet corn (green), field corn (on the cob), celery, beet tops, beans (string beans), Swiss chard, oat straw (used as packing material), dahlias, gladioli and chrysanthemums, are commonly transported through the regular channels of trade, and may easily serve as agencies for carrying the insect into new localities.

CHARACTER AND EXTENT OF INJURY.

Corn.

The following explanation, concerning the terms herein applied to different parts of the corn plant, may be of assistance. The corn plant is monœcius, bearing both staminate (male) and pistillate (female) flowers, separate, but both occur on the same plant. The corn tassel bears the male flowers and the corn silks are the female flowers. The cornstalk consists of nodes (joints) and internodes (intermediate spaces). A single leaf grows from each node. Each leaf is composed of three distinct parts, — the sheath, the ligula and the blade. The sheath is the part of the leaf surrounding the stalk, and, beginning at a node, extends upward nearly to the next node, where it joins the long narrow blade of the leaf. Although the sheath surrounds the stalk, the edges merely overlap and are never grown together. The ligula is a thin, upward continuation of the sheath, above its junction with the blade, at the point where the sheath ends and the blade begins. The blade is the broad, flat portion of the leaf. The pedicel is that portion of the plant by which the ear is attached to the stalk. The pith is the soft, cork-like substance filling the interior of the stalk, between the internodes.

Kinds of Corn injured.

In Massachusetts the larvæ of the European corn borer have been observed to attack sweet corn, field corn and fodder corn.

In the area now infested by the insect, sweet corn is grown to a greater extent than either field corn or fodder corn, and most of the observations herein recorded were made on sweet corn.

Wherever field corn has been found within the infested area the plants have been attacked by the insect with the same degree of severity as has been sweet corn, and, due to its longer period of growth, the damage to the ears is much greater than to the ears of sweet corn.

Only one field of fodder corn was located within the infested area, and this was attacked by the insect to a slight extent. This infestation was on the edge of the infested area in the town of Topsfield, where only an occasional larva of the European corn borer was found.

Injury to the Tassel.

The newly hatched larva of the European corn borer first attacks the unopened staminate buds of the tassel. After entering and feeding upon the internal succulent parts of several staminate buds, it enters the stalk 2 or 3 inches above the lower branches of the tassel, and tunnels upward for 2 or 3 inches. It then returns to its original entrance and tunnels toward the base of the plant.

Within a few days the larva completely consumes the central pith of the tassel stalk, soon causing a break at the point where it originally entered. The broken-over portion of the tassel still remains partly attached to the plant, and in this condition its yellow-white color and broken-over position make it a very conspicuous object in a field of corn in contrast to the green color and upright position of tassels not infested.

This type of injury indirectly affects the formation of corn kernels on the cob by greatly reducing the amount of pollen. In the process of fertilization, pollen from the tassel must fertilize the corn silk in order that kernels may develop. It is apparent that if pollen is not present in large enough quantities the resulting ear of corn will show a lack of fully developed kernels. Field counts made in badly infested areas showed that as high as 61 per cent of the corn tassels had been broken over and were barren of pollen. This high percentage of injury was more common on late corn than on early corn, due, perhaps, to the greater number of larvæ present. Out of a total of 3,810 tassels, counted in a field of late season, sweet corn at West Medford, Mass., 2,344 tassels, or 61 per cent, were infested and broken over. Many ears of corn from this field were noticeably small in size and with few kernels, even though not themselves directly injured by the insect. Much of this loss is believed to have been caused by the injury to the tassel, although this belief is contrary to the opinion of botanists consulted. It is apparent that botanists must reverse their opinion in this matter.

Injury to the Stalk.

In nearly all cases the terminal internode, bearing the tassel, furnishes sufficient food for the full development of a single larva. Other larvæ, if present in the same tassel, are forced to leave and tunnel in the lower parts of the plant for food. Their operations are generally confined to the upper two-thirds of the stalk, but, if numerous, they may extend their tunneling to the very base of the stalk, or even into the upper part of the taproot. When several larvæ are feeding in the same stalk the pith is nearly, if not entirely, consumed, and the interior of such a stalk is found to be practically hollow. There is a tendency for the larvæ to work in the internodes of the stalk, but, when necessary, they commonly pierce, and feed upon, the nodes. This latter observation is contrary to published records on the habits of the species by European writers.

A total of 75 corn plants, growing in a badly infested field at West

Medford, Mass., were carefully dissected and counts made of the larvæ found therein, in order to secure data concerning the number infesting single plants. A maximum of 117 larvæ, and a minimum of 7, with an average of 46 larvæ per plant, were found in these 75 plants. These plants composed a total of 17 hills taken at random in different parts of the field. A maximum number of 311 larvæ, and a minimum of 151, with an average of 206 larvæ per hill, were found in these 17 hills of corn. The 17 hills of corn composed of 75 plants contained a total of 3,503 larvæ. The actual count of one-eighth of an acre in this field showed a total of 2,855 plants, or 22,840 plants to the acre. Each of these 2,855 plants was infested to a greater or lesser degree. An average infestation of 46 larvæ per plant, as shown above, means a total of 1,050,640 larvæ of the European corn borer per acre of corn.

Naturally, this extensive injury to the interior of the cornstalk, together with the numerous entrance and exit holes of the larvæ on the surface, weakens the plant to such an extent that it soon breaks over and lies prone upon the ground. The supply of nutriment to the ear is also cut off, causing a small or aborted ear of corn. Even when only a few larvæ are present within the plant, the growth of the stalk and formation of the ear are greatly retarded.

The tunnels left by the larvæ of the European corn borer frequently serve as sources of infection by various rots and fungi, so that the interior of badly infested stalks is sometimes found to be a mass of putrifying matter, occupied by various scavenger insects that have gained admittance to the plant by way of the entrance or exit holes of *P. nubilalis* larvæ.

Injury to the Ear.

The indirect injury to the ear by larvæ of the European corn borer has already been mentioned. This is caused (1) by interference with proper pollenization resulting from larvæ cutting off the tassel, and (2) by internal injury to the stalk, which cuts off the normal supply of nutriment to the ear.

The ear, however, is also directly injured by the external and internal feeding of the larvæ. Frequently the moths of the first generation, and habitually those of the second generation, deposit their eggs directly upon the silk of the ear. The newly hatched larvæ feed first upon the silk, thus contributing to improper fertilization, and later they work their way down into the ear, where they tunnel through all parts of the cob and also feed upon the newly formed kernels. Sometimes eggs are deposited upon the exterior, or husk, of the ear, and the newly hatched larva feeds for a time upon the exterior of the husk before entering the ear, either at its tip end, or between the edges of the leaves of the husk.

The ear is frequently entered by partly grown larvæ, which have left some other plant or another part of the same plant. These larvæ may enter the ear at any point, — its tip end, along the sides, or through the side of the pedicel. In other instances they tunnel directly from the interior of the stalk through the pedicel and into the ear; consequently, the infested ears may not show external indications of injury.

A combination of these larval habits may result in the presence of several larvæ within a single ear. In one instance a total of 15 were found feeding on the interior and exterior of one ear. Extensive feeding of this nature reduces the ear to a soft, decaying condition, totally unfit for market, and unsuitable, even, for feeding to stock. This deterioration is hastened by the introduction of various rots and fungi, which gain entrance to the plant through the holes made by the borers. Even when only a single larva is present within the ear, its feeding renders the ear unfit for market, while its use for seed, or for storage in cribs, is absolutely prevented, owing to the softened condition of the kernels and their tendency to quick decay.

The percentage of ears infested in any given field depends upon the degree of infestation. An actual field count, made in a one-eighth acre plot of sweet corn located at West Medford, Mass., showed that, out of a total of 3,311 ears present in this plot, the entire number were infested, to a greater or lesser degree, by larvæ of the borer. This plot was typical of most of the fields and small garden patches of sweet corn found in the territory where the pest has become well established. It serves as a standard by which to judge the amount of damage to corn that may be expected if the pest is not brought under control.

Injury to the Leaf.

Newly hatched larvæ of the European corn borer may feed upon the upper or lower epidermis of the leaf blade before they enter the buds of the tassel. This type of injury is of no economic importance, except that it offers a possibility for poisoning the young larvæ by application of arsenicals. Partly grown larvæ infrequently tunnel into the midrib of the leaf blade, and also feed between the leaf sheath and the stalk.

Summary of Injury to Corn.

The economic injury to corn may be summarized as follows: —

1. Injury to tassel which results in poor fertilization.
2. Injury to stalk which reduces vitality of plant.
3. Injury to stalk which causes breaking over of plant.
4. Injury to stalk which indirectly affects ear.
5. Injury to ear which directly affects the yield.
6. Injury to silk of ear which results in poor fertilization.

OTHER FOOD PLANTS.

Dock.

In the absence of corn, dock is a common food plant of the first generation of European corn borer larvæ. The plant is represented by at least two different species in the area infested by *P. nubilalis*, and both species are attacked by the insect. It grows plentifully as a weed in cultivated areas, and also in waste places, generally preferring rather moist soil.

The newly hatched borer feeds first upon the tender seed head, or upon the epidermis of the tender leaves. As the larva develops it tunnels through the leaf petiole, and when about half grown enters the main stalk. It then usually tunnels downward, feeding through nodes and internodes, and consuming in its progress nearly all the interior of the stalk. This causes a weakening of the plant which soon breaks over at the point where the larva entered. The broken-over portion soon dies and turns brown in color, thus rendering it a very conspicuous object among plants not infested. A mass of conspicuous yellowish-white frass, extruded by the larva within, generally adheres to the point in the stalk where the larva entered. This serves to distinguish plants infested by *P. nubilalis*, even in instances where the plants do not break over.

The number of dock plants per acre is generally rather limited, so that all plants of this species in a given area are commonly infested, depending, of course, upon the degree of infestation.

Economically, dock is important in that it serves as an early season host plant for the European corn borer in areas where corn is absent. The second generation adults emerging from dock deposit their eggs upon late corn and other commercial crops.

Barnyard Grass.

Barnyard grass is the most important and the most commonly infested weed among the uncultivated hosts of the European corn borer. All parts of the plant, except the root, are fed upon by the larva, including the seed head, the leaves and the stalk. Barnyard grass grows luxuriantly in almost any waste area of ground, or in the spaces between economic plants in cultivated fields. It seems to prefer well-fertilized soil, and under favorable conditions may reach a height of 5 or 6 feet, with a diameter at the base of nearly half an inch. It is very abundant in all parts of the area infested by the European corn borer, and serves as a food plant for both generations of larvæ.

The newly hatched larvæ feed for a short time upon the green buds of the seed head, and also upon the upper or lower epidermis of the leaves. They soon enter the main stalk of the plant, however, and tunnel upward or downward according to their individual preference. A dozen or more are sometimes found in each stalk, and as the stalks grow very thickly clustered together in clumps, a foot or more in diameter, the aggregate number of larvæ infesting each clump of barnyard grass often equals the number normally found in a hill of badly infested corn. Many areas of vacant land, large or small in extent, throughout the infested region, are thickly covered by barnyard grass clumps of this description, which contain untold numbers of the depredating larvæ.

Owing to the small diameter of most barnyard grass stalks, the tunneling of the larva leads to an early collapse of infested stalks, which soon fall to the ground. This forms a mass of intertwined plants very difficult to remove or destroy during clean-up operations.

The chief economic significance of barnyard grass as a food plant of the European corn borer lies in the fact that it serves as a common host of the insect, and aids in its multiplication and distribution in areas where corn is absent.

Pigweed.

Pigweed, or redroot, is commonly found growing among cultivated crops, or closely adjacent thereto. It generally serves as a sort of overflow host plant to accommodate the larger larvæ of the corn borer which have left their original host plant and are seeking other food.

In rare instances newly hatched larvæ are found feeding upon the green seed heads of this plant. This is generally caused by the dislodgment of these larvæ from their original host.

More commonly the plant is attacked by good-sized larvæ which have partly completed their development in other food plants. The stalk is entered at any point along its surface, and the larva tunnels upward or downward in the same manner and with the same results as have been mentioned for other food plants.

Pigweed is not generally infested by the European corn borer with the same degree of severity as are dock and barnyard grass, although it is important economically as an intermediate host of the insect, and may act as a host in the absence of more favored food plants.

Ragweed and Lamb's-quarters.

Ragweed, or hogweed, and lamb's-quarters serve as food plants for the European corn borer in the same manner and extent as has been described for pigweed. The larvæ attack the green seed head and stalk of each of these plants. Lamb's-quarters sometimes grows to a height of 4 or 5 feet, and develops a tough, woody stalk an inch or more in diameter. It is perhaps the hardest and toughest stalk in which the larvæ of the European corn borer have been found.

Both ragweed and lamb's-quarters are found widely distributed throughout the infested area, although the number of plants found in a given space is generally small.

Dahlias.

Larvæ of the European corn borer tunnel through the main stalk and flower stems of dahlias during the late summer and fall. The percentage of dahlias in a given area, infested by the larvæ, is generally very high. In Arlington, and other towns adjacent to Boston, almost every group of dahlia plants was found to be infested by *P. nubilalis* during the past summer. Small larvæ are rarely found in dahlias, most of the damage being done by those which have hatched and fed for a time on other plants in the vicinity, and are about half grown when they enter the dahlia plants. Entrance may be effected at almost any place along the main stalk or flower stem, but the favorite point is at the junction of flower stems with the main stalk. The tunneling larva soon consumes the interior of the infested stalk or stem, and that portion first wilts and then breaks over in a dying condition. It is then very conspicuous in contrast to the stems not infested, and ruins the appearance of dahlia plantings. Half a dozen or more larvæ have been cut from a single dahlia flower stem.

The principal point to be considered in connection with the infestation of dahlia plants by larvæ of the borer is that the species may possibly be disseminated through the medium of cut flowers.

Chrysanthemum and Gladiolus.

The stalks of chrysanthemums and gladioli are tunneled by larvæ of the European corn borer in a similar manner and with the same results as has been described for dahlias. Infested chrysanthemum stalks are commonly found in out-of-door gardens during the late summer and fall, and also in greenhouse plots. This characteristic renders chrysanthemums economically important because of the possibility that the pest may be accidentally spread by transporting recently infested plants which have not yet shown external effects of the larval injury.

Infested gladiolus stalks are found in out-of-door gardens during the late summer, and though not as important economically as chrysanthemums, this plant may also be a source of danger through the accidental transportation of infested plants to areas not yet inhabited by the pest.

Timothy and Foxtail.

Small larvæ of the European corn borer have frequently been found feeding upon the seed heads of timothy and foxtail. This damage is not important economically, except that it affords a host for the larvæ of the pest until they have reached a stage in their growth when they are large enough to attack other food plants. Larvæ of the species have never been observed to feed within the stalks of these plants, and the plants are never noticeably injured.

Miscellaneous Plants.

The stalks of lady's-thumb, burdock, horseweed, beggar-ticks, purslane, crabgrass, mare's-tail, panicgrass, goldenrod, thistle and apple of Peru are often entered and tunneled by partly grown larvæ of the European corn borer. These plants are rather numerous in restricted areas through the infested region, and serve as intermediate hosts of the borer, although the plants themselves are of no economic importance.

Celery.

Nearly full-grown larvæ of the borer have been observed to enter and tunnel the outside stems of celery plants. This injury, however, has been observed in only one field, and in this instance the celery was growing adjacent to a very badly infested field of sweet corn. This corn was inhabited by so many larvæ that the food supply was apparently exhausted, and the larvæ were attracted to the green succulent stems of the celery plants. Several were commonly found in each of the outside stems, but none were found in the stems near the center of the plant.

Similar circumstances to those which resulted in this infestation may be expected to occur from time to time, as celery is frequently grown adjacent to or between the rows of corn plantings.

Celery may be considered an important economic food plant of the European corn borer because of the possibility that plants containing infested stems may be shipped outside the infested area.

Swiss Chard.

The stalk and midrib of the leaves of Swiss chard plants were frequently found infested by the borer under the same circumstances and with the same result as has been recorded in the instance of celery. The injury to Swiss chard, however, was observed in a number of fields in widely separated localities. The green stalks and leaves of this plant are commonly shipped from town to town and must be considered as sources of danger.

Beans.

The pods, immature beans and interior of the vines of bean plants were found infested by larvæ of the European corn borer in several fields. This generally occurred in instances where several crops were planted together, and the bean plants served to accommodate the overflow larvæ from other food plants. The infestation was always found to be very light in character. Under exceptional circumstances the bean plant may become important economically as a host of the borer because of the possibility that larvæ of the species might be transported within the immature pods of string beans.

Potatoes and Tomatoes.

In badly infested areas the larger larvæ of the European corn borer may occasionally be found tunneling the stems of potatoes and tomatoes. Not more than a single larva has ever been observed within a plant, and the injury, so far as observed, is very slight and not at all important commercially.

Beets and Spinach.

Larvæ of the European corn borer are infrequently found tunneling within the leaf stems of beets and spinach during the early fall. This type of injury may be of economic importance because of the possibility that infested plants may be transported for use as greens.

Oats.

The stalks of volunteer oats were found infested by the larger larvæ of the borer in one instance. The injury and its results were similar to that described for other plants with a like habit of growth (pigweed, etc.). Only a very small percentage of oat stalks present was infested.

Oats may become important economically as a food plant of the borer because of the fact that oat straw is often used as packing material.

Turnips.

Large larvæ of the European corn borer were observed feeding upon the outside surface of the tender leaf stems of the turnip. They were not found within the turnip plants, and it is believed that this plant is not at all important as a host of the borer.

DESCRIPTIONS OF THE DIFFERENT STAGES.

The Egg.

Average length, .97 millimeter; average width, .74 millimeter; circular ovate in shape, slightly convex on its upper surface, flat on its lower surface, or conforming to the shape of the object on which it is deposited. Exochorion sculptured with shallow pentagonal or polygonal pits. Endochorion apparently smooth. Color, when first deposited, opaque white, often strongly iridescent. In from eighteen to twenty-four hours after deposition a crescentiform clear space is formed in the center of the egg on its upper surface. About two days before hatching the egg assumes a yellowish tinge, and soon thereafter the developing larva becomes visible and imparts to the egg a yellow-black appearance.

The eggs are commonly deposited in irregular-shaped masses, each egg overlapped by the adjacent ones in the manner of shingles. Each egg mass is composed of from 5 to 50 eggs.

The Larva.

First Instar (see Plate I, Fig. 1). — Average measurements of 11 individuals, newly hatched. Length, 1.6 millimeters; head width, .30 millimeter. Length of head and prothoracic shield, one-fourth total length of larva. Body subcylindrical, opaque white to yellowish green in color. Tubercles large, prominent, pale amber gray. Primary setæ long, amber-colored. Anterior stigmatal tubercle on prothorax bisetose, the upper seta the shorter; subventral tubercle also bisetose, the anterior seta the shorter. Tubercles iv and v are absent on mesothorax and metathorax; coalescent on abdominal segments 1 to 8, inclusive; situated below the spiracle on segments 1 to 7; below and slightly anterior to spiracle on segment 8. Tubercles i*a*–i*b* and ii*a*–ii*b* coalescent on mesothorax and metathorax. Setæ i*a* and ii*a* are shorter than setæ *ib* and ii*b*. Seta iii is of medium length. On the dorsum of abdominal segments 1 to 7, tubercles i and ii form a trapezoidal figure, while on the dorsum of segment 8 they form a nearly rectangular figure. On the dorsum of abdominal segment 9 is a large irregular-shaped, nearly oblong, corneous tubercle bearing a long seta at each of its posterior lateral angles, and a distinct puncture on the median anterior border. The nearly elliptical preanal plate bears two short setæ and one long seta along each of the posterior lateral angles, and one short seta centrally located on each side of the median line. Spiracles protruding, concolorous with tubercles.

Head black or dark brown, declivous and flattened in the newly hatched larva, becoming more rounded as the larva develops. Adfrontal pieces not perceptible in this or succeeding instars until the fifth. Clypeus pale and distinct from frontal piece. Labrum pale, bilobate, with normal arrangement of setæ. Mandibles reddish brown, not protruding. Ocelli six in number, pale and protruding. Antennæ with slight tinge of amber on distal segments.

Prothoracic shield averages .25 millimeter, slightly lighter in color than the head, corneous, almost straight anteriorly, broadly rounded posteriorly. Each half of the shield bears three setæ on the anterior border, two on the lateral posterior border, and one centrally located and near the median line. Bases of setæ surrounded by a black ring. A perceptible indentation, but no division of shield along the middorsal line. Venter of prothoracic segment appears darker owing to presence of dark thoracic shield above.

Thoracic legs, abdominal prolegs, preanal plate and anal prolegs amber. Circle of crotchets on abdominal prolegs broken externally. Thoracic feet and crotchets on abdominal and anal feet pale brown. Thoracic feet corneous.

Second Instar (see Plate I, Fig. 2). — Average measurements of 13 individuals, just molted: Length, 2.625 millimeters; head width, .46 millimeter. Length of head and prothoracic shield, one-sixth total length of larva. Body subcylindrical, amber-white to yellowish green in color. Tubercles large, prominent, pale amber, polished; iv and v present and coalescent on mesothorax and metathorax. Otherwise the arrangements of tubercles and setæ are similar to preceding instar, and remain fairly constant throughout the remaining larval stages. The relative length of the longer body setæ diminishes in each succeeding instar. Spiracles pale amber at center, with black edges. Bases of tubercles and setæ surrounded by a black ring.

Head deflexed. Clypeus pale and distinct from frontal piece. Labrum pale brown. Mandibles reddish brown with black tips. Distal segments of antennæ pale amber, otherwise colorless.

Prothoracic shield averages .414 millimeter wide or nearly equal to that of head. Indentation along middorsal line more pronounced but no division. Venter of prothoracic segment darker.

Thoracic feet and crotchets on abdominal and anal feet dark brown. Preanal plate pale amber.

Third Instar (see Plate I, Fig. 4). — Average measurements of 16 individuals, just molted: Length, 4.75 millimeters; head width, .68 millimeter. Body subcylindrical and darker than preceding instar. Abdominal segments, except 9 and 10, crossed transversely by shallow grooves. Anterior stigmatal and subventral tubercles of prothorax contiguous, nearly concolorous with head and somewhat corneous. Remaining body tubercles as before.

Head deflexed, dark brown in color. Clypeus nearly concolorous with head, and not so distinct from frontal piece. Labrum pale brown.

Prothoracic shield averages .71 millimeter wide. Line of division down middorsal line semi-distinct for one-half distance from anterior border. Venter of prothoracic segment dark.

Thoracic legs, abdominal legs and preanal plate as before.

Fourth Instar (see Plate I, Fig. 6). — Average measurements of 12 individuals, two or three days after molting: Length, 12.5 millimeters; head width, 1.03 millimeters. Body cylindrical, varies in color from opaque white to pale or dark amber. Some individuals show indistinct median and subdorsal longitudinal reddish brown or gray lines on the dorsum. Tubercles of medium size, arranged similar to second instar. Prothoracic tubercles not contiguous, slightly darker than remaining body tubercles. Spiracles nearly concolorous with tubercles.

Head slightly paler than preceding instar. Clypeus not distinctly marked off from front, concolorous with head, trapezoidal; average height, .12 millimeter, average width, .47 millimeter. Labrum dark brown. Mandibles dark brown, not protruding. Distal segments of antennæ dark amber, otherwise nearly colorless.

Prothoracic shield averages .98 millimeter wide, distinctly divided along middorsal line, slightly paler in color than before, and often assuming a yellowish tinge on anterior border. Venter of prothoracic segment slightly darker than venters of remaining segments.

Fifth Instar (see Plate II, Fig. 8). — Average measurements of 13 individuals, three days after molting: Length, 14.46 millimeters; head width, 1.66 millimeters. Body cylindrical, varies in color from dusky opaque white to light pink, with distinct median and subdorsal longitudinal reddish brown, gray or pink lines on the dorsum. Tubercles medium and distinct, pale at center and surrounded by a dusky black ring which in turn is surrounded, on the abdominal segments, by a wider, pale amber-colored band. Tubercles on thorax uniformly dark amber, same arrangement as before. Spiracles nearly concolorous with tubercles.

Head polished dark brown, not quite as high as wide. Clypeus distinctly marked off from front, central area paler than head; average height, .18 millimeter, average width, .66 millimeter. Adfrontal pieces distinct for first time and extend to the vertex. Labrum dark brown at base, paler at free edge. Mandibles dark brown, protrude slightly. Distal segments of antennæ amber, otherwise colorless.

Prothoracic shield averages 1.72 millimeters wide, more distinctly divided than preceding instar. General color pale brown to pale yellow, polished, with dark brown areas. Anterior border pale yellow. The median posterior margin bears a triangular area, and two large irregular areas are present in a shallow depression near the lateral corners of the shield. The posterior and lateral margins of the shield are dark brown. Bases of setæ surrounded by a distinct black ring. Venter of prothoracic segment only slightly darker than venters of remaining segments.

Prothoracic legs concolorous with head, mesothoracic legs dusky externally, metathoracic legs pale amber. Abdominal and anal legs as before.

Sixth Instar (see Plate II, Fig. 10). — Average measurements of 9 individuals, four days after molting: Length, 19.95 millimeters; head width, 2.19 millimeters. Body cylindrical, abdominal segments, except 9 and 10, crossed transversely by deep grooves. General color darker than preceding instar, varying from dusky pale brown to dark brown or pink. Median line narrow, dark brown and very distinct; subdorsal line vague in outline, broad, pale brown or pink; lateral lines narrow, pale brown. Tubercles medium and darker than general color of body, more pronounced on thorax. Arrangement of prothoracic tubercles and setæ as before. Tubercles i*a*–i*b*, ii*a*–ii*b* and iv–v are coalescent on mesothorax and metathorax. Setæ i*a* and ii*a* are very much shorter than setæ i*b* and ii*b*. Seta v is very much shorter than seta iv, while setæ iii and vii are of medium length. Tubercles iv–v are coalescent on abdominal segments 1 to 8, inclusive, situated below the spiracle on segments 1 to 7; below and slightly anterior to spiracle on segment 8. On dorsum of abdominal segments 1 to 7, tubercles i and ii form a trapezoidal figure, as before, while on dorsum of segment 8 these tubercles form nearly a rectangular figure. Large corneous tubercle on dorsum of segment 9, and preanal plate on dorsum of segment 10, with setal arrangement as before. The setæ on lateral anterior borders of prothoracic shield, setæ i*b* and ii*b* of mesothorax and metathorax, the setæ on dorsal tubercle of segment 9, and the long setæ on preanal plate are nearly twice as long as any others present.

Head polished brown, with pale brown areas on epicranial lobes. Clypeus as before; average height, .27 millimeter, average width, .84 millimeter. Adfrontal pieces more distinct. Labrum, mandibles and antennæ as before.

Prothoracic shield averages 2.34 millimeters wide. Colored areas on shield similar to preceding instar, with additional small pale brown depressions along each side of median line. The position and form of these colored areas are variable. Venter of prothorax concolorous with venters of remaining segments.

Thoracic, abdominal and anal legs as before.

The Pupa.

Average length of ♂, 13 to 14 millimeters; of ♀, 16 to 17 millimeters. Average width of ♂, 2 to 2.5 millimeters; of ♀, 3.5 to 4 millimeters.

Color varies from light to dark brown, venter comparatively smooth, dorsum darker in color with fine transverse wrinkles. Form elongate with peculiar "shouldered" appearance of the body, caused by the great width of the thorax as compared with width of the head. Appendages firmly cemented to the body. Wings, maxillæ, antennæ and mesothoracic legs, together with metathoracic legs which lie beneath, are approximately equal in length and extend to the middle of the fourth abdominal segment. Prothoracic legs terminate midway between the head and the tip of the other appendages. Dorsum of thorax very dark, not shiny, with a distinct smooth, slightly elevated ridge extending along the dorso-median line. The fifth, sixth and seventh abdominal segments bear a ridge near the anterior border, which extends completely around the segment. On the dorsum of each of the fourth, fifth and sixth abdominal segments is a transverse line of four bicuspidate projections of the body wall. A pair of proleg scars are visible on the venter of the fifth and sixth abdominal segments. The last segment of the pupa terminates in a dark brown, or black, cremaster, which bears at its extremity eight small spines, arranged transversely, which curve forward at their tips and serve to attach the pupa to its cocoon. Length of these curved spines about .19 millimeter. Spiracles ellipsoidal, prominent and borne on abdominal segments 2 to 7, inclusive. The pupa is always enveloped in a thin cocoon.

The terminal segments of ♂ and ♀ pupæ differ in shape and in arrangement of plates.

The Adult.

Alar expanse: male, 24–26 millimeters; female, 29–32 millimeters. Length of body, 13–14 millimeters in both sexes.

Head above covered with light yellowish brown scales, except adjacent to compound eyes, where scales are white; ventral surface, white. Labial palpi porrect; second segment covered with dense projecting, cinnamon-brown to light brown scales attenuated to a point forward; terminal segment concealed; basal segment covered with white scales. An imaginary line, passing through the axis of the body tangent to the lower edge of the compound eye, will divide the labial palpi into two portions according to their coloration, the upper portion being cinnamon-brown, the lower portion white. Maxillary palpi light brownish, erect, slightly dilated and converging at apex. Tip of labial palpi and maxillary palpi the same color in female, labial palpi somewhat darker in male. Proboscis long, with cream-colored scales, usually tightly coiled and almost completely hidden by labial palpi when viewed from the side. Antennæ filiform, two-thirds the length of the front wing, with a longitudinal stripe of cream-colored scales on the posterior side; opposite side brownish.

Terminal half of antenna often curled in preserved specimens. Ocelli present.

Dorsum of thorax cinnamon-brown in male, light yellowish brown in female. Fore legs white exteriorly, fuscous internally. Ventral surface of thorax, mesothorax and metathoracic legs covered with white hairs and scales in both sexes. Inner spurs twice the length of outer ones. Fore wings as wide as hind wings, costal margin gently curved toward apex, anal angle rounded, inner margin straight.

Fore wing of female dull yellow, the costa and inner two-thirds of wing more or less streaked with dull brown; a serrate brown line crosses the wing at about its outer third, followed externally by a narrow yellow band, the outer margin of which is also serrate; external to this is a brown band shot through with yellow toward the outer margin. Hind wing grayish brown, with a rather broad, pale band at the outer third, beginning a little behind the costa and extending nearly to the hinder margin. In some specimens the fore wing colors are dull yellow and cinnamon-brown, and the hind wings very pale brown with faint irregular streaks or shades of darker, instead of as described above; beneath, pale, with faint reproduction of the yellow band on the fore wing, its margins darker but not serrate. Male fore wing somewhat more reddish brown with a yellow discal spot, and a yellow serrate band at the outer third beginning a little behind the costa and often cut into outwardly by inward extensions from the darker color outside, tending to break it into a row of lunate spots; hind wings more gray, with the band of the female hind wing tending to disappear at its ends and become a large, elongate, rather oval area; beneath, dark, with a faint reproduction of the light band of the fore wing and a lighter shade corresponding to the oval area of the hind wing; also light along the inner margin over quite a width.

Fore wing (Plate II, Fig. 12): 1*a* very weakly developed, bending slightly forward toward 1*b* at the basal fourth of the latter; 4 and 5 fairly near at base, 5 arising considerably behind the middle of the outer end of the cell; cross vein closing end of cell nearly obsolete from 5 forward; 7 and 8 about as near each other at base as 4 and 5, 8–9 arising from the end of the cell, but almost in contact with 10, which it follows closely for some distance before diverging and forking, 8 extending almost exactly to the apex. Base of 1*b* enlarged, bearing a tuft of long, forwardly directed hairs beneath. Hind wing (Plate II, Fig. 13) with three anal veins; veins 3, 4 and 5 arising close together; cross vein forming outer end of cell strongly re-entrant: vein 6 leaving the cross vein just before it unites with 7–8. Frenulum in male consists of one long, stout spine; in female (Plate II, Fig. 14), of two long spines and a shorter, more slender one. Ventral surface covered with whitish scales. Dorsum of male cinnamon-brown (excepting first two segments which are amber yellow); of female, amber yellow, the posterior border of each segment with a fringe of white.

LIFE HISTORY.

First Generation.

Incubation Period.

The eggs are deposited in masses of from 5 to 50 on the under surface of the upper blades of corn or other food plants. They hatch, on an average, in 7 days, with a maximum of 9 days and a minimum of 5 days (see Table II), the duration of the incubation period depending somewhat upon temperature conditions.

Table II. — *Duration of Incubation Period — First Generation.*

Date of Deposition, 1918.	Date of Hatching, 1918.	Incubation Period (Days).	Date of Deposition, 1918.	Date of Hatching, 1918.	Incubation Period (Days).
May 24, . .	June 2, . .	9	May 29, . .	June 5, . .	7
May 25, . .	June 3, . .	9	May 31, . .	June 6, . .	6
May 26, . .	June 3, . .	8	June 1, . .	June 7, . .	6
May 26, . .	June 3, . .	8	June 1, . .	June 6, . .	5
May 26, . .	June 3, . .	8	June 2, . .	June 8, . .	6
May 27, . .	June 3, . .	7	June 2, . .	June 8, . .	6
May 28, . .	June 4, . .	7	June 3, . .	June 10, . .	7
May 28, . .	June 4, . .	7	June 3, . .	June 11, . .	8
May 28, . .	June 4, . .	7	June 4, . .	June 11, . .	7
May 28, . .	June 4, . .	7	June 5, . .	June 12, . .	7
May 28, . .	June 4, . .	7	June 6, . .	June 15, . .	9
May 29, . .	June 6, . .	8	June 7, . .	June 15, . .	9
May 29, . .	June 6, . .	8	June 8, . .	June 16, . .	8
May 29, . .	June 6, . .	8	June 9, . .	June 18, . .	9

Average length of incubation period, ...	7.43 days.
Maximum length of incubation period, ...	9 days.
Minimum length of incubation period, ...	5 days.

Larval Period.

In the course of their development the larvæ feed upon, and within, various parts of their food plant, and pass through from five to eight instars. Out of a total of 20 individuals reared from egg to pupa, in life-history cages 14 individuals required five instars to complete their larval growth, 3 required six instars, 2 required seven instars and 1 individual eight instars. It is probable that, under field conditions, there are normally five or six instars in this generation.

In 20 life-history cages the average duration of the first instar was

7.25 days; second instar, 6 days; third instar, 5 days; fourth instar, 6.5 days; fifth instar, 13 days; sixth instar, 14 days; seventh instar, 8 days; and eighth instar, 13 days. The average duration of the total larval period was 44 days, with a maximum of 57 and a minimum of 35 days (see Table III). The duration of each instar and the total duration of the larval period depend upon temperature conditions.

After reaching full growth the larva forms a cocoon within which it pupates.

TABLE III. — *Duration of Larval Instars — First Generation.*

PIGWEED (*Amaranthus*).

DATE OF HATCHING, 1918.	DURATION OF LARVAL INSTARS IN DAYS.								Date of Pupation, 1918.	Days in Larval Period.	Sex.
	First.	Second.	Third.	Fourth.	Fifth.	Sixth.	Seventh.	Eighth.			
June 4,	6	5	5	8	7	14	–	–	July 19	45	♀
June 10,	7	5	6	7	7	10	6	died	–	–	–
June 10,	7	5	6	6	5	7	11	–	July 26	46	♀
June 10,	6	4	7	5	6	7	7	13	Aug. 4	55	♀

DOCK (*Rumex*).

DATE OF HATCHING, 1918.	First.	Second.	Third.	Fourth.	Fifth.	Sixth.	Seventh.	Eighth.	Date of Pupation, 1918.	Days in Larval Period.	Sex.
June 15,	4	7	6	6	30	–	–	–	Aug. 7	53	♂
June 15,	4	7	6	9	19	–	–	–	July 30	45	♀
June 15,	4	9	4	6	5	18	–	–	July 31	46	♀
June 15,	4	10	4	8	12	–	–	–	July 23	38	♂
June 15,	5	7	5	11	29	–	–	–	Aug. 11	57	–
June 15,	4	8	5	8	4	28	–	–	Aug. 11	56	♀
June 15,	6	6	5	9	19	–	–	–	July 30	45	♂
June 16,	10	5	4	8	9	–	–	–	July 22	36	♀
June 16,	10	5	6	7	15	–	–	–	July 29	43	♀
June 16,	10	4	4	6	13	–	–	–	July 23	37	♀
June 16,	10	5	6	7	8	–	–	–	July 22	36	♀
June 16,	9	5	5	5	13	–	–	–	July 22	36	♂
June 16,	9	5	4	5	12	–	–	–	July 21	35	♂
June 16,	10	6	6	7	13	–	–	–	July 28	42	♀
June 16,	10	6	5	5	17	–	–	–	July 29	43	♂
June 16,	10	5	4	7	17	–	–	–	July 29	43	♀
Average,	7.25	6	5	6.5	13	14	8	13	–	44	–

Average duration of larval period,	44 days.
Maximum duration of larval period,	57 days.
Minimum duration of larval period,	35 days.

Pupal Period.

Pupation generally occurs within the tunnels made by the larva, although occasionally it occurs in masses of larval frass, or between closely attached leaves. The duration of the pupal period, in the instance of 49 individuals confined in life-history cages, averaged 8.5 days, with a maximum of 10 and a minimum of 7 days, depending upon temperature conditions (see Table IV).

TABLE IV. — *Duration of Pupal Period — First Generation.*

Number of Observation.	Date of —		Number of Days.	Sex.	Number of Observation.	Date of —		Number of Days.	Sex.
	Pupation.	Emergence.				Pupation.	Emergence.		
1–120	July 15	July 24	9	♂	26–147	July 21	July 29	8	♂
2–121	July 15	July 25	10	♂	27–149	July 22	July 29	7	♀
3–122	July 16	July 24	8	♂	28–150	July 22	July 30	8	♀
4–123	July 16	July 25	9	♂	29–151	July 22	July 30	8	♀
5–124	July 16	July 25	9	♂	30–152	July 22	July 30	8	♀
6–125	July 16	July 25	9	♂	31–153	July 22	July 30	8	♀
7–126	July 16	July 26	10	♀	32–154	July 23	July 31	8	♂
8–129	July 17	July 25	8	♀	33–155	July 23	July 31	8	♂
9–130	July 17	July 25	8	♀	34–156	July 23	July 31	8	♀
10–131	July 18	July 26	8	♀	35–157	July 23	July 31	8	♂
11–132	July 18	July 25	7	♀	36–158	July 23	July 31	8	♀
12–133	July 18	July 27	9	♂	37–159	July 23	Aug. 1	9	♂
13–134	July 18	July 25	7	♀	38–160	July 23	July 30	7	♀
14–135	July 19	July 29	10	♂	39–161	July 23	July 30	7	♀
15–136	July 19	July 27	8	♀	40–162	July 24	Aug. 2	9	♂
16–137	July 19	July 28	9	♂	41–163	July 23	Aug. 2	10	♂
17–138	July 18	July 27	9	♀	42–164	July 24	Aug. 2	9	♀
18–139	July 19	July 28	9	♀	43–165	July 24	Aug. 3	10	♀
19–140	July 19	July 28	9	♀	44–166	July 25	Aug. 4	10	♀
20–141	July 19	July 28	9	♀	45–167	July 25	Aug. 4	10	♀
21–142	July 20	July 28	8	♀	46–168	July 26	Aug. 4	9	♂
22–143	July 20	July 27	7	♀	47–169	July 27	Aug. 5	9	♀
23–144	July 20	July 28	8	♀	48–171	July 27	Aug. 6	10	♂
24–145	July 20	July 28	8	♀	49–172	July 27	Aug. 5	9	♀
25–146	July 20	July 29	9	♂					

Average length of pupal stage, ... 8.551 days.
Maximum length of pupal stage, ... 10 days.
Minimum length of pupal stage, ... 7 days.

Adult Period.

Soon after emerging from the pupa the female moth begins the oviposition of second generation eggs. With 13 females, confined in individual life-history cages, the average duration of the period, between emergence from the pupa and the first oviposition, was 3.2 days, with a maximum of 9 days and a minimum of 1 day (see Table V).

TABLE V. — *Oviposition by Female Moths in Rearing Cages — First Generation.*

Number of Moths.	Sex.		Date of —			Number of Days —			Total Number of Eggs.
	♂	♀	Emergence, 1918.	First Oviposition.	Last Oviposition.	Before Oviposition.	Of Oviposition.	From Emergence to last Oviposition.	
2	1	1	July 25	July 29	Aug. 19	4	22	25	494
3	2	1	July 27	July 29	Aug. 14	2	17	18	590
3	2	1	July 27	July 29	Aug. 11	2	14	15	510
3	2	1	July 27	July 29	Aug. 3	2	6	7	415
2	1	1	July 29	Aug. 1	Aug. 11	3	11	13	594
2	1	1	July 29	July 30	Aug. 16	1	18	18	592
2	1	1	July 29	July 31	Aug. 10	2	11	12	132
2	1	1	July 29	July 30	Aug. 8	1	10	10	626
2	1	1	July 30	Aug. 3	Aug. 26	4	24	27	280
2	1	1	July 30	Aug. 8	Aug. 21	9	14	22	602
2	1	1	July 30	Aug. 3	Aug. 25	4	23	26	786
2	1	1	July 30	Aug. 2	Aug. 13	3	12	14	559
2	1	1	July 30	Aug. 4	Aug. 16	5	13	17	903
29	16	13	–	–	–	–	–	–	–
Average, ...						3.2	15	17.23	545
Maximum, ...						9.0	24	27.00	903
Minimum, ...						1.0	6	7.00	132

The duration of the oviposition period of these 13 females averaged 15 days, with a maximum of 24 and a minimum of 6 days (see Table V).

The average length of life of 23 female moths, confined in cages with male moths, approximating field conditions as nearly as possible, was 18 days, with a maximum of 28 and a minimum of 6 days. The average length of life of 27 male moths in these same cages was 14 days, with a maximum of 35 and a minimum of 3 days (see Table VI).

TABLE VI. — *Length of Life of Male and Female Moths in Captivity — First Generation.*

LENGTH OF LIFE IN DAYS.	Number of Male Moths.	Number of Female Moths.	LENGTH OF LIFE IN DAYS.	Number of Male Moths.	Number of Female Moths.
3,	2	–	17,	2	2
5,	2	–	18,	2	1
6,	2	2	19,	3	1
8,	1	–	23,	1	1
9,	2	–	24,	–	3
10,	3	1	26,	–	1
11,	1	1	27,	–	2
12,	–	1	28,	–	2
13,	1	1	34,	1	–
14,	2	2	35,	1	–
16,	1	2			
			Totals,	27	23

Average length of life: male moths, 13.74 days; female moths, 18.26 days.
Maximum length of life: male moths, 35 days; female moths, 28 days.
Minimum length of life: male moths, 3 days; female moths, 6 days.

It is believed that the duration of adult life, as well as the period before and during oviposition, depends considerably upon the accessibility of the opposite sex, temperature conditions, and the facilities afforded for oviposition. Nevertheless, the data given above were secured under as near natural conditions as could be arranged in cages, and the averages are believed to represent very closely the actual duration of adult periods in the field. These figures are important, showing as they do the comparatively long period during which the adults deposit their eggs.

Life Cycle Summary.

A complete life cycle is here considered to be the total period elapsing from the deposition of eggs of one generation to the time of deposition of eggs of the next generation. Therefore the average duration of the life cycle of the first generation of the European corn borer during 1918 was 63 days, with a maximum of 85 and a minimum of 48 days, as shown by the following table: —

TABLE VII. — *Life Cycle Summary of First Generation.*

	Average.	Maximum.	Minimum.
Incubation period in days,	7.43	9.00	5.00
Larval period in days,	44.05	57.00	35.00
Pupal period in days,	8.51	10.00	7.00
Adult preoviposition period in days,	3.20	9.00	1.00
Total,	63.19	85.00	48.00

SECOND GENERATION.

Incubation Period.

The eggs are deposited in masses on various parts of the food plant selected for oviposition. They hatch, on an average, in 6 days, with a maximum of 8 and a minimum of 4 days (see Table VIII). Duration of the incubation period depends upon temperature conditions.

TABLE VIII. — *Duration of Incubation Period — Second Generation.*

OBSERVATION NUMBER.	Number of Eggs.	DATE OF —		Duration of Incubation Period in Days.
		Deposition, 1918.	Hatching, 1918.	
200,	188	July 29	Aug. 2	4
201,	136	July 29	Aug. 2	4
202,	107	July 29	Aug. 3	5
203,	149	July 29	Aug. 3	5
204,	40	July 30	Aug. 5	6
205,	87	July 30	Aug. 6	7
206,	137	July 30	Aug. 5	6
207,	51	July 31	Aug. 6	6
208,	46	July 31	Aug. 6	6
209,	69	July 31	Aug. 6	6
210,	128	July 31	Aug. 6	6
211,	87	July 31	Aug. 6	6
212,	71	Aug. 1	Aug. 6	5
213,	102	Aug. 2	Aug. 7	5
214,	103	Aug. 2	Aug. 7	5
215,	79	Aug. 2	Aug. 7	5
216,	67	Aug. 3	Aug. 8	5
217,	89	Aug. 3	Aug. 7	4
218,	78	Aug. 4	Aug. 8	4
219,	112	Aug. 4	Aug. 8	4
220,	101	Aug. 5	Aug. 9	4
221,	151	Aug. 5	Aug. 9	4
222,	128	Aug. 6	Aug. 12	6
223,	77	Aug. 6	Aug. 12	6
224,	64	Aug. 7	Aug. 14	7
225,	223	Aug. 8	Aug. 14	6
226,	75	Aug. 9	Aug. 15	6
227,	205	Aug. 9	Aug. 15	6
228,	–	Aug. 10	Aug. 16	6

TABLE VIII.— *Duration of Incubation Period — Second Generation* — Con.

Observation Number.	Number of Eggs.	Date of — Deposition, 1918.	Date of — Hatching, 1918.	Duration of Incubation Period in Days.
229,	100	Aug. 11	Aug. 17	6
230,	–	Aug. 12	Aug. 17	5
231,	–	Aug. 13	Aug. 19	6
232,	–	Aug. 14	Aug. 22	8
233,	–	Aug. 15	Aug. 23	8
234,	–	Aug. 22	Aug. 27	5
235,	142	Aug. 23	Aug. 29	6
236,	43	Aug. 23	Aug. 29	6
237,	128	Aug. 23	Aug. 29	6
238,	76	Aug. 24	Aug. 30	6
239,	50	Aug. 24	Aug. 31	7
240,	117	Aug. 24	Aug. 30	6
241,	163	Aug. 25	Aug. 30	5
242,	141	Aug. 25	Sept. 1	7
243,	95	Aug. 25	Sept. 1	7
244,	46	Aug. 26	Sept. 3	8
245,	29	Aug. 26	Sept. 3	8
246,	95	Aug. 26	Sept. 3	8
247,	68	Aug. 26	Sept. 3	8
248,	126	Aug. 26	Sept. 3	8
249,	19	Aug. 27	Sept. 4	8
250,	27	Aug. 27	Sept. 4	8
251,	49	Aug. 27	Sept. 4	8
252,	96	Aug. 27	Sept. 4	8
253,	70	Aug. 27	Sept. 4	8
254,	68	Aug. 29	Sept. 6	8

Average duration of incubation period,	6.13 days.
Maximum duration of incubation period,	8 days.
Minimum duration of incubation period,	4 days.

In the course of their development the larvæ of the second generation feed in a manner similar to that described for the first generation. They pass through four or five instars before the advent of severe winter weather, which halts their activities and indefinitely prolongs the duration of the last instar or instars. According to data secured from 25 larvæ, reared in life-history cages from eggs to the time when their activities ceased, the average duration of the first instar was 5.4 days; second instar, 4.2 days; third instar, 5 days; fourth instar, 9 days; and fifth instar, 10 days. The average duration of the total larval period was 26 days, with a maximum of 32 days and a minimum of 20 days (see Table IX). The duration of each instar and the total duration of the larval period depend upon temperature conditions.

TABLE IX. — *Duration of Larval Instars and Activity to Nov. 30, 1918 — Second Generation.*

BARNYARD GRASS (*Echinochloa crus-galli*).

DATE OF HATCHING, 1918.	DURATION OF LARVAL INSTARS IN DAYS.					Date of Pupation, 1918.	Days in Larval Period to Date.	Activities to Nov. 30, 1918.
	First.	Second.	Third.	Fourth.	Fifth.			
August 6, . .	3	5	8	4	11	–	31	Spun web Sept. 24.
August 6, . .	3	4	7	5	13	Sept. 14	32	♂ adult Oct. 14.
August 6, . .	3	5	8	8	–	–	24	Died Nov. 19.
August 6, . .	3	5	7	5	–	–	22	Died Sept. 6.
August 9, . .	5	6	5	6	10	–	32	Spun web Sept. 11.
August 9, . .	4	5	7	5	7	–	28	Died Nov. 15.
August 9, . .	5	6	5	13	–	–	29	Spun web Nov. 30.
August 9, . .	5	6	5	9	–	–	25	Died Nov. 3.
August 9, . .	5	5	6	9	–	–	25	Spun web Oct. 8.
August 9, . .	6	6	5	9	–	–	26	Spun web Oct. 10.
August 14, . .	6	4	4	9	8	–	31	Still feeding Nov. 30.
August 14, . .	7	3	4	7	–	Oct. 1	21	Not emerged Nov. 30.
August 14, . .	6	4	4	11	–	–	25	Spun web Oct. 21.
August 14, . .	6	4	4	14	–	–	28	Still feeding Nov. 30.
August 14, . .	6	3	7	10	–	–	26	Still feeding Nov. 30.
August 14, . .	6	4	4	11	–	–	25	Spun web Oct. 16.
FOXTAIL GRASS (*Setaria glauca*).								
August 14, . .	6	4	3	7	–	Sept. 5	20	♂ adult Nov. 4.
August 14, . .	6	5	4	9	–	–	24	Still feeding Nov. 30.
August 14, . .	7	3	3	8	–	–	21	Died Nov. 30.
August 14, . .	6	3	6	13	–	–	28	Spun web Oct. 14.
August 14, . .	6	3	4	10	–	–	23	Died Nov. 30.
August 14, . .	6	4	4	13	–	–	27	Spun web Nov. 8.
August 14, . .	7	3	4	11	–	–	25	Died Nov. 30.
August 14, . .	6	3	4	9	–	–	22	Died Nov. 18.
August 14, . .	7	3	4	9	–	–	23	Spun web Nov. 2.
Average, . .	5.4	4.2	5	9	9.8	–	25.7	– –

Average duration of larval period to date, ...	25.7 days.
Maximum duration of larval period to date, ...	32 days.
Minimum duration of larval period to date, ...	20 days.

Three of the larvæ, confined in the life-history cages mentioned, formed pupæ during September and October (see Table IX). This is believed to have been caused by the abnormal conditions which inevitably exist in confinement. No pupæ of this generation were found in the field during the dissection of many hundreds of badly infested plants throughout the months of October, November and early December, 1918.

The second generation larvæ of the borer normally pass the winter within their host plants as full-grown, or nearly full-grown, larvæ in the fifth and sixth instars. With the advent of warm weather in the spring the larvæ begin feeding again, and pupate within a short period of time thereafter.

Pupal Period.

Pupation occurs in a similar manner to that described for the first generation. The duration of the pupal period for 35 individuals confined in life-history cages averaged 17 days, with a maximum of 20 and a minimum of 14 days (see Table X), depending upon weather conditions.

TABLE X. — *Duration of Pupal Period, Second Generation.*

Number of Observation.	Date of —		Number of Days.	Sex.	Number of Observation.	Date of —		Number of Days.	Sex.
	Pupation.	Emergence.				Pupation.	Emergence.		
1, . .	May 6	May 24	18	♂	19, . .	May 17	June 3	17	♀
2, . .	May 8	May 26	18	♀	20, . .	May 18	June 3	16	♂
3, . .	May 10	May 24	14	♀	21, . .	May 18	June 4	17	♂
4, . .	May 10	May 27	17	♂	22, . .	May 18	June 4	17	♀
5, . .	May 11	May 29	18	♂	23, . .	May 18	June 4	17	♀
6, . .	May 11	May 28	17	♀	24, . .	May 18	June 4	17	♀
7, . .	May 12	May 28	16	♀	25, . .	May 18	June 4	17	♂
8, . .	May 12	May 29	17	♀	26, . .	May 18	June 4	17	♀
9, . .	May 12	June 1	20	♂	27, . .	May 19	June 4	16	♀
10, . .	May 13	May 31	18	♂	28, . .	May 20	June 6	17	♀
11, . .	May 13	May 31	18	♀	29, . .	May 20	June 6	17	♂
12, . .	May 14	May 30	16	♀	30, . .	May 21	June 7	17	♀
13, . .	May 14	June 2	19	♂	31, . .	May 22	June 7	16	♂
14, . .	May 14	June 2	19	♀	32, . .	May 25	June 12	18	♂
15, . .	May 15	June 2	18	♀	33, . .	May 25	June 9	15	♀
16, . .	May 17	June 2	16	♀	34, . .	May 31	June 17	18	♀
17, . .	May 17	June 3	17	♂	35, . .	June 2	June 19	17	♀
18, . .	May 17	June 3	17	♀					

Average length of pupal stage, ...	17.11 days.
Maximum length of pupal stage, ...	20 days.
Minimum length of pupal stage, ...	14 days.

Adult Period.

The female moth begins the oviposition of first generation eggs within a few days after emerging from the pupa. With 15 females, confined in individual life-history cages, the average duration of the period between emergence from the pupa and the first oviposition was 3.6 days, with a maximum of 7 days and a minimum of 1 day (see Table XI).

TABLE XI. — *Oviposition by Female Moths in Rearing Cages, Second Generation.*

Number of Moths.	Sex.		Date of —			Number of Days —			Total Number of Eggs.
	♂	♀	Emergence.	First Oviposition.	Last Oviposition.	Before Oviposition.	Of Oviposition.	From Emergence to last Oviposition.	
8	4	4	May 21	May 24	June 10	3	18	20	1,261
3	2	1	May 24	May 29	June 13	5	16	20	389
3	2	1	May 24	May 28	June 23	4	7	10	190
3	2	1	May 24	May 31	June 6	7	7	13	157
3	2	1	May 24	May 28	June 3	4	7	10	348
3	2	1	May 25	May 28	June 17	3	21	23	727
3	2	1	May 25	May 28	June 16	3	20	22	713
3	2	1	May 26	May 29	June 3	3	6	8	223
2	1	1	May 28	May 29	June 9	1	12	12	107
3	2	1	May 29	June 2	June 16	4	14	18	586
3	2	1	June 1	June 3	June 10	2	7	8	210
3	2	1	June 1	June 8	June 24	7	16	22	137
40	25	15	–	–	–	–	–	–	–
Average,						3.66	13.66	16.4	336.53
Maximum,						7.00	21.00	23.0	727.00
Minimum,						1.00	6.00	8.0	107.00

The duration of the oviposition period of these 15 females averaged 14 days, with a maximum of 21 and a minimum of 6 days (see Table XI).

The average length of life of 29 female moths, which were confined in cages with male moths, approximating field conditions as nearly as possible, was 17 days, with a maximum of 29 and a minimum of 8 days. The average length of life of 40 male moths in these same cages was 13 days, with a maximum of 29 and a minimum of 6 days (see Table XII).

TABLE XII. — *Length of Life of Male and Female Moths in Captivity.*

LENGTH OF LIFE (DAYS).	Number of Male Moths.	Number of Female Moths.
6,	3	–
7,	2	–
8,	6	2
9,	4	2
10,	4	1
11,	4	1
12,	3	4
13,	1	2
14,	2	–
15,	1	3
16,	–	1
17,	–	1
18,	–	1
19,	1	–
20,	1	1
21,	3	–
22,	–	4
23,	1	–
24,	1	2
25,	–	2
26,	–	–
27,	2	–
28,	–	–
29,	1	2
Total,	40	29

Average length of life of male moths, 13.1 days; of female moths, 16.86 days.
Maximum length of life of male moths, 29 days; of female moths, 29 days.
Minimum length of life of male moths, 6 days; of female moths, 8 days.

These records were secured in the same manner as has been described in the instance of the first generation adults, and they have the same application and qualification.

Life Cycle Summary.

It is rather difficult to give any accurate figures as to the duration of the life cycle of the second generation of the European corn borer, owing to the varying amount of time spent by the larva in an inactive condition during the late fall, winter and early spring. An attempt will be made, however, to approximate the correct figures by combining the results of the life-history studies as to the duration of the different periods of this generation during the early spring of 1918 and the summer and fall of 1918 up to November 30.

According to these records the average duration of the second generation of the European corn borer was 52.6 days, with a maximum of 67 and a minimum of 39 days, as shown by the following table: —

TABLE XIII. — *Life Cycle Summary of Second Generation.*

	Average.	Maximum.	Minimum.
Incubation period in days,	6.13	8.00	4.00
Larval period in days,[1]	25.70	32.00	20.00
Pupal period in days,	17.11	20.00	14.00
Adult preoviposition period in days,	3.66	7.00	1.00
Total period in days,	52.60	67.00	39.00

[1] Excluding winter period of inactivity.

SEASONAL HISTORY AND DEVELOPMENT.

NUMBER OF GENERATIONS.

There are two annual generations of the European corn borer in Massachusetts, a generation here being considered to begin with the egg and terminate with the moth of the same generation.

Eggs of the first generation are deposited during late May or early June, and the resulting larvæ pupate about the middle of July. The moths emerge during late July and early August to deposit eggs of the second generation.

These eggs are deposited, therefore, during late July or early August, and the resulting larvæ feed on, or within, their food plant until the advent of severe winter weather. Feeding is resumed with the coming of warm weather in the spring, and the larvæ pupate about the middle of May. The second generation moths emerge during late May or early June, and deposit eggs for the first generation.

A few moths of the second generation have emerged in life-history cages during September and October (see Table IX), but these individuals died without depositing eggs. Under exceptional circumstances it is possible that moths emerging at this time may deposit eggs for a third generation, but this has not yet been observed.

SEASONAL HISTORY.

The European corn borer passed the winter of 1917–18 as nearly full-grown larvæ of the second generation within their tunnels in various food plants.

The first pupa of the second generation was found in the field May 6, and the majority of the overwintering larvæ pupated between May 15 and 20.

The first moth of the second generation was observed in the field on May 16. Moths began to emerge from indoor cages May 18, and maximum emergence occurred during the period from June 1 to 4. The last emergence of second generation moths was recorded on July 9, from laboratory cages (see Table XV).

Oviposition of second generation moths occurred within a few days after emergence, and extended over a period of about two weeks. Eggs of the first generation were first secured in life-history cages on May 24 (see Table XI).

Larvæ of the first generation were first secured in life-history cages on June 2 (see Table II), and were observed for the first time in the field on June 13.

The first pupa of the first generation was found in the field on July 11, and in life-history cages on July 15. Maximum pupation took place between July 19 and 23 (see Table IV).

Emergence of first generation moths began about July 23 and reached its maximum between July 27 and August 4. The last emergence of first generation moths was recorded from indoor cages on August 29 (see Table XIV), and from corn in the field on September 6.

On July 29 the first eggs of the second generation were secured in life-history cages (see Table V). Eggs of this generation were first observed in the field on August 13.

Larvæ of the second generation were first secured in life-history cages on August 2 (see Table VIII), and were observed for the first time in the field on August 13. On this date some of the larvæ in the field were in the second and third instars. On September 2 many of the larvæ in the field were in the fifth and sixth instars. When the last field observations were made, on November 30, most of the larvæ were in the fifth and sixth instars, and in this stage of their development they probably will pass the winter of 1918–19.

Seasonal Abundance.

The larvæ of the borer reach their greatest abundance and do the most damage to corn and other host plants during the late summer and fall. The damage to early corn by larvæ of the first generation during June and July is much less than the damage to late corn by those of the second generation during August and September. The same is true for the other host plants infested by the insect.

There is quite a heavy mortality of overwintering larvæ, due to natural causes, and this when added to the high percentage of overwintering larvæ destroyed by control measures and cultural practices, greatly reduces the numbers of the pest that remain to perpetuate the species in the spring. Consequently the first generation of larvæ is much smaller in numbers each year than the second generation of the preceding year.

HABITS OF LARVÆ.

Hatching.

About a day before hatching takes place, the black eye spots and reddish mandible tips of the developing larva may be seen through the semitransparent chorion of the egg. A few hours before hatching, the head and thoracic shield become black and are observed to occupy a central position in the egg. The body segmentation and the black spines on the body of the larva are also plainly discernible. At this time the developing larva is curled up inside the egg with its mandibles resting upon the next to the last abdominal segment. These mandibles soon begin to move laterally, and the larva straightens itself out in such a manner that the mandibles are brought into contact with the eggshell. A slit in this is soon made, and the larva crawls forth. After hatching, the larva feeds, to some extent, upon the empty eggshell, but has not been observed to entirely devour it.

Habits when attacking Corn.

First Generation.

The newly hatched larva crawls about over the surface of the corn blade on which it hatched, stopping here and there to eat a small area of the epidermis on either the upper or lower surface of the blade (see Plate I, Fig. 1). These small areas are usually bordered by veins on each side and are longer than wide.

During its travels the larva gradually approaches the growing crown of the plant, and, upon reaching it, descends between the rolled leaf blades, or cone, composing the crown, and feeds internally upon the young and succulent epidermis of the unfolding leaf blades. If the tassel is present within the cone the first instar larvæ may feed upon the epidermal cells composing the flower buds, but only rarely do larvæ of this instar enter the buds.

When ready to molt, the first instar larva spins a thin, silken molting cocoon in some protected location near its last feeding place, within which it molts to the second instar.

Upon emerging from its molting cocoon this larva immediately attacks the staminate flower buds if the tassel is present within the crown. If the tassel is not present it feeds on the tightly rolled leaf blades composing the crown in a similar manner to that described for the first instar, except that larvæ of the second instar are able to eat entirely through the blade, and do not confine their feeding to the epidermis. When the tassel is present within the crown the second instar larva bores a hole in the side of one of the staminate flower buds and feeds upon the internal succulent contents. Entrance to the bud may be effected from the top, at the base or from the side, several buds are destroyed in turn by each larva. During the process of feeding within the buds considerable frass is extruded, and this becomes webbed together with the silk spun by the larva in traveling from bud to bud, and forms a certain amount of protection for the larva. This webbing together of frass for possible protection is characteristic of the second generation larva, as, although larvæ of the first and later instars are capable of spinning a web, they do not use it for purposes of protection while feeding.

When ready to molt, the second instar larva spins a molting cocoon, within which it molts to the third instar. This molting cocoon may be located within a single, hollowed-out flower bud, or may be situated beneath the webbed-up frass from several flower buds.

The third instar larva feeds at first within the staminate buds of the tassel in a similar manner to that described for the second instar larva, but, when a little older, it may enter the terminal spike of the tassel, 1 or 2 inches above the last branch, and tunnel within this spike, and a small mass of frass collects at the point of entrance and renders the injury conspicuous. Instead of entering the tassel, many third instar larvæ tunnel within the midrib of the leaf blade. These tunnels are never more than 1 or 2 inches in length, and closely resemble the injury to the tassel spike. Whether the third instar larva tunnels in the terminal spike, in the midrib of the leaf, or continues feeding in the ends, appears to be arbitrary with the individual.

The third instar larva may molt to the fourth instar, either within its tunnel or in some protected place outside. If molting occurs within its tunnel, a molting cocoon is not formed, but a silken partition is spun across the entrance hole. If molting occurs in some protected place outside the tunnel, a typical molting cocoon is formed, and the larva molts to the fourth instar in a similar manner to that described for the preceding ones.

After molting to the fourth instar the larva usually enters the main stalk of the tassel 1 or 2 inches from its base. Sometimes it enters the terminal internode at the point where the first leaf blade joins its sheath. Later the terminal internode of the corn plant grows so that this entrance point, instead of being present at the junction of the leaf blade and the leaf sheath, is found 5 or 6 inches above that point. After cutting an entrance hole in the side of the stalk the larva tunnels out a small, spherical cell, which occupies nearly all the interior of the stalk at this point. From this it usually tunnels upward for 2 or 3 inches above the entrance hole, and then returns and tunnels downward. During this feeding a large amount of frass is pushed out of the entrance hole and is held there by means of small silken strands spun by the larva. This large mass of yellow-white frass is very conspicuous, and serves to identify infested tassels, even before they break over. Eventually the tassel becomes broken over at the point where the fourth instar larva entered the terminal internode.

The fourth instar larva molts to the fifth instar within its tunnel, and only spins a silken partition across its entrance, thus using its tunnel for a molting cocoon.

The fifth instar larva may complete its larval development within the terminal internode. The number of larval instars varies with different individuals, five being sufficient to complete the larval growth in some individuals, while six, or even seven or eight, instars are passed through in other cases. In the majority of instances, especially when an abundant supply of food is available, the fifth instar is the last and longest of the larval instars. During this, or the succeeding instars, the larvæ sometimes wander about and do their greatest amount of damage to the plant. Some individuals leave the terminal internode and tunnel through the lower parts of the stalk; some tunnel from the terminal internode down through the intervening nodes into the lower part of the stalk; while others enter the stalk at various places along its length and tunnel upward or downward according to their individual preference. The junction of the leaf sheath and node is a favorite point of entrance, although this is by no means universal. Frequently the larva enters a stalk and tunnels out a cavity, only to abandon it and enter the plant at a different point. The stalk may be tunneled by the larvæ to its base, or even into the taproot, so that corn stubble is often infested and must be considered a source of danger in clean-up operations.

During their wanderings the larger larvæ very often descend the plant until they reach the side branch, or pedicel, on which the ear is borne. Here they may enter the main stalk or may enter the pedicel and tunnel into the ear. Some enter the ear directly by boring through the husk, later feeding on the immature kernels or tunneling through the cob. In other instances the ear is entered at the tip end, and the larvæ tunnel through the kernels and the cob. Apparently the ear is very much favored as a food by the larvæ.

In instances when the fifth instar larvæ molt into the sixth, seventh or eighth instars (see Table III), the molting process takes place in the same manner and location as has been described for the fourth to fifth instar molt.

The habits of the larvæ vary greatly with different individuals and under different environments. For this reason the preceding remarks are intended to give only an idea of their usual activities in this stage, and their habits when attacking corn. In general, it may be stated that they may attack all parts of the corn plant except the fibrous roots, and that this damage may occur in an indefinite number of ways by larvæ of the different instars.

Second Generation.

When attacking corn the habits of the second generation larvæ are essentially the same as have been described for those of the first generation.

The only exception is that a large proportion of the larvæ hatch from eggs which have been deposited directly upon the silk or husk of the immature ears. They feed first upon the tender leaves of the husk, and upon the silk, and then tunnel through all parts of the ear. This type of injury is of great economic importance, especially in sweet corn or that grown for seed. The amount of damage to corn by larvæ of the second generation is, therefore, infinitely greater than that caused by those of the first generation, due to the greater numbers of the second generation and their habit of attacking the ears directly.

The nearly full-grown larvæ winter over within their tunnels in the stalk, in the ear or in the taproot. They do not generally spin any protective cocoon, but remain quiescent during the cold weather. Feeding is resumed during the warm portions of pleasant days in early spring, but the larvæ return temporarily to their quiescent state during cold nights or inclement and cold spring weather. The hardened condition of stalks and ears during the spring does not appear to present any difficulties to them, as they tunnel through all parts of the plant with the same apparent ease as when the plants were comparatively soft and green the preceding season. Cobs of seed corn, which had been stored on the cob all winter and were very hard and dry, contained living larvæ of the borer in April, 1918. That they had been feeding during the warm periods of the early spring was evidenced by the mass of frass extruding from their tunnels. This occurrence will serve to illustrate the danger of disseminating the pest by the transportation of corn on the cob.

Habits when attacking Dock.

The first instar larva of the European corn borer feeds, to some extent, on the tender seed heads of the dock plant, and also upon the epidermis of the leaves, but soon works its way down between the main stalk and a leaf sheath. Here the first molt occurs, and the second instar larva feeds on the leaf sheath, the basal part of the leaf petiole, and on the small secondary stalks which arise at the junction of the leaf and the stalk. When the leaf petiole is tender enough the second instar larva usually tunnels into it and molts into the third instar, either in this location or at the base of the leaf petiole when it has been unable to effect an entrance. The third instar larva usually tunnels in the leaf petiole and molts to the fourth instar within its tunnel. Occasionally the third instar larva does not feed within the leaf petiole, but enters the main stalk at the junction of the petiole and stalk. Normally, the larva does not enter this main stalk until the fourth instar is reached. After entering the stalk it usually tunnels downward through the nodes and internodes, practically consuming the interior of the stalk. The remaining instars are passed, and the larva becomes full grown and pupates, within this tunnel. A large quantity of frass is extruded by the larva through the entrance hole, and becomes webbed into the axial flowers situated between the main stalk and the petiole. This accumulation of frass makes infested dock plants very conspicuous, even before the upper portion of the plant breaks over at the entrance hole of the larva.

By the 1st of August nearly all of the dock plants are dead, so the activities of the European corn borer in this plant are confined to the first generation.

Habits when attacking Lady's-thumb.

In this common host plant of the European corn borer the first instar larva tunnels directly into the main stalk at a point about 1 or 2 inches below the terminal leaves. Soon after the plant is attacked it may easily be distinguished from those not infested, as the terminal stalk withers and droops above the point where the small, first instar larva entered. After entering the stalk it tunnels downward, molting within the tunnel as it develops in size. This tunnel is not continuous, owing to the fact that the larva emerges from the stalk at will, and enters again at a point nearer the base. It usually tunnels exclusively in the internodes of this plant, very rarely passing through a node. In this particular the habits of the larva, when attacking lady's-thumb, are distinctive because the node is commonly tunneled in other plants.

Habits when attacking Barnyard Grass.

The habits of the European corn borer larvæ, when attacking barnyard grass, are very similar to those that have been detailed in the injury to dock, except that the larger ones, instead of continuing to feed on their original host, often leave the stalks of barnyard grass, where they have partially completed their development, and enter others.

Barnyard grass commonly serves as a host for the second generation larvæ until the middle of October. At this time it becomes dry and hard, and many of the larvæ desert it for more attractive food plants growing in the vicinity, though a large percentage of the original number present continue feeding in the lower parts of the plant, and may be found inside the base of the stalk, below the level of the ground, as late as November 30. It is believed that the nearly full-grown larvæ pass the winter in this location, although complete data on this point will be lacking until observations are made in the spring of 1919.

Superficial observers have frequently stated that barnyard grass is entirely deserted by larvæ of the European corn borer during the late fall season, but close examination will reveal many at the bases of the stalk. In this position they are very difficult to destroy by ordinary clean-up methods.

Molting.

When feeding on, or near, the surface of its food plant, especially during the early instars, the larva spins a molting cocoon within which it molts. This is formed of thin, silken strands, and is located in any protected place. When tunneling inside its food plant the larva does not form a molting cocoon, but merely closes the entrance to the tunnel with a thin, silken partition. It then molts inside this tunnel near its last feeding place.

The process of molting varies in detail with the different instars, but in general is as follows. After all preparations to secure protection have been made, the larva enters a semi-quiescent state during which the head capsule becomes pushed forward until a distinct non-contractile, white band appears between the head and the shield. After remaining in this condition approximately twelve to twenty-four hours the old larval skin splits longitudinally just back of the head capsule, and, as a result of squirming movements from within, slips down and off the molting larva. When nearly free of the old larval skin the larva easily brushes off the old larval head mask, or remains of the head capsule.

The newly molted larva is colorless, with an opaque, white head capsule and thoracic shield. In the course of two or three hours its body assumes the characteristic markings for the instar, while the head and thoracic shield darken and become fully pigmented.

After completing its emergence and coloring the larva remains quiet until the body chitin becomes hard, and then resumes its activities.

Length of Larval Life without Food.

Newly hatched larvæ of the European corn borer lived a maximum of two days in life-history cages without food or water.

Nearly full-grown larvæ, isolated in glass vial cages, without food or water, lived a maximum of thirty days during the active season.

This latter characteristic is important with relation to the possible transportation of infested material to localities not infested by the insect. The long period of life without food would allow larvæ to survive under very adverse conditions, and to start new colonies of the insect when opportunity afforded.

Unusual Habits.

Large larvæ of the European corn borer will eat their way through an ordinary cork stopper and escape from confinement. They are unable, however, to make any impression upon a cotton plug, and are easily confined in glass vials when these are plugged with cotton.

Larvæ also eat through paper and pasteboard. On one occasion a full-grown larva, which had escaped from an indoor cage, tunneled through heavy pasteboard surrounding a bottle, and pupated between the bottle and its covering.

Full-grown larvæ have been observed crawling along the ground at some distance from any possible food plant. In cases of necessity these larvæ could probably travel a considerable distance.

Large larvæ have been found underneath clods of earth and underneath rubbish in badly infested fields, due possibly to some agency which forced them to leave their natural protection within the food plant.

Infested cornstalks were buried in the soil to a depth of 6 inches during the spring of 1917. Within a few days the larvæ deserted the buried cornstalks and made their way to the surface.

Although the larger larvæ normally feed within the plant, occasionally individuals are found feeding on its exterior. This is especially true of the full-grown larvæ just before pupation. At this time they are frequently found feeding on the silk and on the outer husk of the ear.

PUPATION.

Location of Pupa.

Normally the pupa of the European corn borer is found inside the tunnel made by the larva, and not far from its last feeding place. A small per cent of the full-grown larvæ, however, leave the interior of the plant when attacking corn and pupate in some protected place near by, such as the silk of the ear; between the husks of the ear; in a fold of the leaf blades; between two overlapping leaf blades; in the frass clinging to the tassel; in the frass at junction of leaf blade and leaf sheath; between the leaf sheath and stalk; and on the surface of the ear in the hollow made by the feeding larvæ.

Though in corn most of the larvæ pupate within their tunnels in the stalk or in the pedicel of the ear, many pupæ are found inside the cob and in the upper part of the taproot.

Cocoon Formation.

Most of the following remarks concerning cocoon formation apply only when the larva forms its cocoon and pupates within the larval tunnel.

When the larva reaches full growth and is ready for pupation it cuts a circular exit hole to the surface of the plant. It then spins a silken partition across this exit hole from within, and this partition serves to block the outside entrance to its pupal chamber. It then retreats about 2 inches into its tunnel, and forms the base of its pupal chamber by packing the tunnel with a layer of frass about an inch thick. A silken partition is then spun on top of this protecting layer, and frequently another transverse partition of silk is spun about a quarter of an inch above this lower one. After thus closing both ends of the tunnel the larva proceeds to coat the walls of its pupal chamber with a very thin layer of silk, and then spins a single internal partition, also of silk, across the upper part of the pupal chamber and parallel to the exit hole. The larva then constructs two slanting partitions in the lower part of its pupal chamber, which intersect each other and form a partition resembling the letter "Y."

After completing the bottom partitions of the pupal chamber the larva turns around and begins forming the upper ones. These are quite similar to the lower, but are usually more complicated and more substantial. They consist of a series of four or five intersecting partitions of silk which meet in the center to form a letter "Y", and make an angular roof over the head of the larva. The cocoon is then complete. About three or four days are usually required by the larva for its formation.

After completing the upper partitions of its pupal chamber the larva attaches its anal legs firmly to the angle of the "Y" in the bottom partition, and then passes into a semi-quiescent state.

Changes undergone by the Larva previous to Pupation.

In the semi-quiescent state the larva is very sluggish, but is still capable of locomotion. Soon after entering this stage the head starts to bend downward, and the mouth parts become ventral instead of anterior. The second thoracic segment becomes swollen, and the third thoracic and first abdominal segments become compressed as a result of pressure exerted at the anterior and posterior ends of the larva. The second and third abdominal segments remain about normal, while the fourth to seventh become enlarged and swollen, and show distinctly the outlines of the pupal abdomen. At the termination of the semi-quiescent stage, which lasts for about twenty-four hours, the larval head is fully inflexed and the use of both thoracic and abdominal legs is lost. The larva then enters the true quiescent state.

In this stage the larva is not capable of locomotion, but has the characteristic movements of a pupa. Soon after entering this stage the contents of the terminal segments of the larva shrink away from the larval body wall to form the terminal segments of the pupa. At this time the anal legs consist of only the external chitinous covering, with their crotchets firmly attached to the bottom silken partition. When disturbed the larva twitches and turns with a movement resembling that of the pupa, while the empty anal legs remain attached to the silk and are often twisted around each other during the twisting movements of the larva. At this time the abdominal legs are flush with the venter, and the thoracic legs are folded close to the body. The quiescent stage requires from twelve to twenty-four hours for its completion, and then the larva begins the process of pupation.

Process of Pupation.

After a few straining movements forward, and as a result of pressure exerted from within, the larval skin suddenly splits along the dorsal line of the head and thoracic segments, and also down each side of the frontal head plate. After a few wriggling movements the larval skin slips down to the terminal segment, which then is liberated. As soon as it is freed from the larval skin the newly formed pupa turns around two or three times, thus firmly attaching its cremaster to the angle of the lower silken partition in the pupal chamber, at the point formerly occupied by the anal feet of the larva. A timed individual required two and one-half minutes to shed its larval skin, except the terminal segment, and the total time required to completely shed this skin and attach the cremaster was eight minutes.

Changes undergone by the Pupa.

The newly formed pupa is white in color, with a longitudinal pink line down the dorsum. Transverse pink lines extend across the center of the dorsum of each abdominal segment, but fade away laterally. The wing pads are yellow with a tinge of pink. The venter of the abdomen is creamy white throughout. The cremaster and its spines, and also the chitinous braces arising from the last segment, are dark red.

About one hour after pupation the transverse pink lines gradually widen and become darker in color, until the dorsum, except at the union of segments, is yellowish red. At this time the venter is almost pure white, but soon begins to turn pinkish yellow in the posterior half of each abdominal segment. This color then extends to include the entire venter of each abdominal segment. The terminal abdominal segment assumes its permanent color at this time. As permanent coloration proceeds, the dorsum of the thorax and abdomen, together with the wing pads, turn a darker red, and soon assume their permanent color. In approximately five or six hours after its formation the pupa is fully colored, and retains this coloration until about three or four days before the emergence of the moth. At this time it becomes very much darker and shows the adult markings.

HABITS OF ADULTS.

Emergence of the Moths.

After loosening its appendages the emerging moth pushes off the head cap of the pupal skin by exerting pressure from within, and frees itself until the head and eyes are visible. Here the moth rests for a few seconds before struggling completely out of the pupal skin. About two or three minutes are required for the moth to entirely free itself. At this time the wings of the moth are only partly developed, and are practically the size of the pupal wing pads. In this condition the moth escapes from the cocoon and crawls to the surface of the plant, providing pupation occurred within interior tunnels. After reaching the surface the moth obtains a foothold and assumes a perpendicular position. It is never found in a horizontal position at this time. The wings then lengthen and widen gradually, meanwhile being brought vertically over the body and held in this position until fully expanded. After reaching their full development and expansion the wings are lowered to their normal position of rest, and within a few hours the moth is ready to assume its adult activities.

Maximum adult emergence generally occurs very early in the morning, and the moths seldom emerge at any other time, unless the early morning hours are rather cold. In this event the moths are delayed in emerging until the early forenoon. A few, however, have been observed to emerge late in the afternoon.

Copulation.

Copulation occurs within twenty-four hours after the sexes emerge from the pupa, and at frequent intervals throughout the life of the adult, — thirteen to eighteen days' average (see Tables VI and XII). Late afternoon or evening, when the adults are most active, is the usual time for copulation. The act is accomplished in a similar manner to that of other lepidopterous adults.

Polygamy experiments were tried during the summer of 1918, but no definite data were secured as to the number of females fertilized by each male. Bearing in mind the long period of adult life, however, it is probable that each male will fertilize several females.

PROPORTION OF SEXES.

First Generation.

A total of 317 first generation pupæ were collected from the field in July, 1918, and confined in individual cages. From these a total of 317 first generation adults emerged, of which 136, or 42.9 per cent, were males, and 181, or 57.1 per cent, were females (see Table XIV).

TABLE XIV. — *Proportion of Sexes and Time of Emergence of Moths, First Generation.*

DATE OF EMERGENCE, 1918.	Number of Males.	Number of Females.	Total Emergence.
July 23,	1	–	1
July 24,	4	–	4
July 25,	5	6	11
July 26,	2	3	5
July 27,	9	8	17
July 28,	10	14	24
July 29,	14	22	36
July 30,	9	27	36
July 31,	14	15	29
August 1,	2	–	2
August 2,	8	17	25
August 3,	4	8	12
August 4,	5	7	12
August 5,	2	7	9
August 6,	4	4	8
August 7,	1	7	8
August 8,	4	3	7
August 9,	1	2	3
August 10,	3	1	4
August 11,	2	2	4
August 12,	2	–	2
August 13,	3	3	6
August 14,	6	3	9
August 15,	5	1	6
August 16,	–	1	1
August 17,	–	2	2
August 18,	–	–	–
August 19,	–	–	–
August 20,	1	1	2
August 21,	3	1	4
August 22,	4	4	8
August 23,	4	1	5
August 24,	1	7	8
August 25,	2	3	5
August 26,	–	–	–
August 27,	1	–	1
August 28,	–	–	–
August 29,	–	1	1
Total,	136	181	317

Total emergence, 317 adults.
Total males, 136, or 42.9 per cent.
Total females, 181, or 57.1 per cent.

A total of 49 first generation pupæ were reared from full-grown, first generation larvæ collected in the field during July, 1918, in order to secure data as to duration of the pupal period. From this material a total of 49 first generation adults emerged, of which 19, or 38.8 per cent, were males, and 30, or 61.2 per cent, were females (see Table IV).

On the night of August 6–7, 1918, 17 first generation moths were captured at a trap light. Of these, 7, or 41.2 per cent, were males, and 10, or 58.8 per cent, were females.

Thus out of a total of 383 first generation adults, 162, or 42.3 per cent, were males, and 221, or 57.7 per cent, were females.

Second Generation.

In April, 1918, two barrels of badly infested cornstalks were collected and placed in the laboratory in order to secure data as to adult emergence, proportion of sexes, etc. From these two cages 307 second generation adults emerged, of which 160, or 52.1 per cent, were males, and 147, or 47.9 per cent, were females (see Table XV).

TABLE XV.—*Proportion of Sexes and Time of Emergence of Moths, Second Generation.*

DATE OF EMERGENCE, 1918.	Number of Males.	Number of Females.	Total Emergence.	DATE OF EMERGENCE, 1918.	Number of Males.	Number of Females.	Total Emergence.
May 18,	1	–	1	June 11,	–	–	–
May 19,	6	4	10	June 12,	1	5	6
May 20,	5	2	7	June 13,	2	2	4
May 21,	2	5	7	June 14,	1	2	3
May 22,	3	6	9	June 15,	2	3	5
May 23,	1	1	2	June 16,	1	3	4
May 24,	14	7	21	June 17,	3	–	3
May 25,	7	2	9	June 18,	1	–	1
May 26,	9	3	12	June 19,	1	2	3
May 27,	5	1	6	June 22,	1	1	2
May 28,	2	5	7	June 23,	1	–	1
May 29,	8	7	15	June 24,	1	2	3
May 30,	2	–	2	June 25,	–	2	2
May 31,	2	6	8	June 26,	–	3	3
June 1,	12	8	20	June 27,	–	2	2
June 2,	12	19	31	June 28,	1	–	1
June 3,	17	16	33	June 29,	2	–	2
June 4,	9	7	16	June 30,	1	1	2
June 5,	3	1	4	July 1,	1	–	1
June 6,	6	3	9	July 2,	–	3	3
June 7,	2	4	6	July 4,	1	–	1
June 8,	4	2	6	July 5,	–	1	1
June 9,	3	1	4	July 9,	–	1	1
June 10,	4	4	8	Total,	160	147	307

Total emergence, 307 adults.
Total males, 160, or 52.1 per cent.
Total females, 147, or 47.9 per cent.

A total of 35 second generation pupæ were reared from full-grown second generation larvæ collected in the field during May, 1918, in order to secure data as to duration of the pupal period. From this material 35 second generation adults emerged, of which 13, or 37.3 per cent, were males, and 22, or 62.7 per cent, were females (see Table X).

Thus out of 342 second generation adults, 173, or 50.5 per cent, were males, and 169, or 49.5 per cent, were females.

It will be noted that, in the instance of the 725 adults of both generations represented by these figures, the sexes were present in nearly equal proportions, there being 335 males and 390 females.

Flight.

Character of Flight.

Both sexes of the European corn borer adults are capable of flight. They habitually fly very close to the ground, a tendency that is caused, perhaps, by the fact that the plants upon which the females deposit their eggs do not generally reach a height of more than 6 or 8 feet. When disturbed in their hiding places during the day the adults fly close to the ground, in a curious zigzag manner, for a distance of 10 or 20 feet, and then seek cover again under some object.

It is rather difficult to observe the flight of the adults during the time of their maximum activity in the early evening. Such observations as were made, however, indicated that adults normally fly very low, even when seeking food plants upon which to deposit their eggs. The males apparently are more active than the females, and fly for greater distances and at higher altitudes. The character of their flight at this time is similar to that which has been described in the instance of moths disturbed from their hiding places during the day.

Distances of Flight.

Under most conditions the moths cover a very short distance in each flight, the maximum observed in any single flight being about 50 yards. The females make a series of short flights in search of food plants on which to deposit their eggs, so that the total distance covered by a female in a series of flights may be considerable. The males make a similar series of flights in their search for the females.

Effect of Wind on Flight of Moths.

It is not believed that the moths are carried any considerable distances by the wind, although the general direction in which the insect has spread, since its introduction into Massachusetts, has been with the prevailing winds.

Meteorological records show that these winds during May, June, July and August are from the south and the southwest. The fact that the insect has spread more rapidly toward the north and the northeast than in any other direction would tend to indicate that the flight of the moths is influenced by the wind to some extent.

The habit of the moth of flying close to the ground would seem to reduce the possibility of wind spread to a minimum, but future observations may show other influencing factors.

Time of Maximum Activity.

During the day the moths remain inactive. They may commonly be found hiding on the underside of the foliage of their food plant, or in strips of grassland and low weeds growing along the field borders and ditches of cultivated areas. They also remain inactive during cool periods, and also during high winds. They become active in the late afternoon, and reach their greatest period of activity about dusk.

Attraction of Moths to Trap Lights.

On the night of August 6–7, 1918, a trap light was placed midway, and 50 feet distant, from two areas of sweet corn which contained hundreds of first generation adults. These had recently emerged from early corn and were at the period of their greatest activity. The trap light was started at 8 P.M. At this time the moths were actively flying around among the corn plants. The first moth was caught at 8.45 P.M. Observations were continued until 11.30 P.M., and the trap light was left burning until 8 A.M. the next morning. The total catch from this trap light experiment was 17 moths, of which 7 were males and 10 were females. Subsequent dissection showed that all of the females were gravid.

The trap light used in the experiment was yellow in color. Examination of blue arc lights along the streets in the vicinity of badly invested areas failed to show that the moths were attracted to the blue lights to any greater extent than has been detailed for the yellow light.

OVIPOSITION.

The females of the European corn borer begin ovipositing about three days after emerging from the pupa (see Tables V and XI). Oviposition generally occurs during the late afternoon or early evening.

DETAILS OF OVIPOSITION.

The female assumes a position on the under surface of a leaf blade, and bends the end of the abdomen down, meanwhile extruding the ovipositor until its tip comes in contact with the leaf blade. The tip of the ovipositor is fleshy and circular. Around its periphery extends a circle of amber-colored hairs. After selecting the spot on which the egg is to be deposited the female stands still and vibrates the ovipositor until the spherical-shaped egg appears at its tip. The egg is then quickly pushed against the leaf and tamped down into place by the ovipositor, which at the same time flattens it. This act changes the egg from its original spherical shape into a more flattened one. From 5 to 50 eggs are thus deposited in a flat egg-mass, each egg overlapping the adjoining one in the manner of shingles. The female rarely changes her position during the oviposition of an egg-mass, as the flexibility of the abdomen allows quite a radius of action.

Distribution of Egg Masses.

During its period of fertility the female deposits a varying number of egg-masses, each mass being composed of from 5 to about 50 eggs. These are generally placed on the under sides of the leaves of several different plants, but in some instances all of the eggs may be deposited on the same plant. When selecting plants for egg deposition the female apparently prefers certain plants to the exclusion of others belonging to the same species.

In life-history cages the daily rate of oviposition varied with different females and according to the temperature conditions. In some instances a single female deposited several egg-masses in twenty-four hours, while in other instances a period of several days elapsed between the deposition of successive egg-masses.

Total Number of Eggs deposited by Each Female.

First Generation.

In life-history cages 13 female moths of the first generation deposited an average of 545 eggs each. The maximum number of eggs deposited by a single female was 903, and the minimum, 132 (see Table V).

Second Generation.

In life-history cages 15 female moths of the second generation deposited an average of 337 eggs each. The maximum number of eggs deposited by a single female was 727, and the minimum, 107 (see Table XI).

Duration of Fertility.

The duration of fertility is here considered to be the period between the first and last deposition of eggs.

First Generation.

The duration of fertility of 13 female moths of the first generation that were confined in life-history cages during July and August, 1918, averaged fifteen days, with a maximum of twenty-four days and a minimum of six days (see Table V).

Second Generation.

The duration of fertility of 15 female moths of the second generation that were confined in life-history cages during May and June, 1918, averaged 13.66 days, with a maximum of twenty-one days and a minimum of six days (see Table XI).

The long period of fertility of the female moths in both generations of the European corn borer is important because it results in larvæ of several different instars being present in the same field, and often on the same plant at the same time. This may be an important consideration in any control measures that have for their object the destruction of the young larvæ before they enter the plant.

The long period of fertility also increases the chances that gravid females may start new infestations of the insect by being carried outside of the infested area.

PARASITES.

European Records of Parasites.

European literature contains very few records of parasites bred from the European corn borer in any of its stages. Most of the literature on this species emphasizes the absence of any parasites.

Robin and Laboulbene (11) mention the fact that one of their colleagues, M. Jules Fallon, reared many specimens of *P. nubilalis* (Botys) from larvæ to adults during several consecutive years prior to 1879, but secured no parasites, either hymenopterous or dipterous, from any stage of the insect.

Jablonowski (16) records breeding a parasite fly, *Ceromasia interrupta* Rdi., from the larva of *P. nubilalis.* The author states that "the insect is not much infested by parasites in Hungary."

Kollar (6) mentions that some Ichneumonidæ have been bred from the insect.

Records of Parasites in Massachusetts.

No parasites were bred from the egg of the European corn borer during the investigations in Massachusetts.

Parasites of the Larva.

In Massachusetts four different species of dipterous parasites belonging to the Tachinidæ have been bred from larvæ of the borer. These Tachinids were determined by Dr. J. M. Aldrich of the United States National Museum as *Masicera myoidea* Desv., *Exorista pyste* Walk., *Exorista nigripalpis* Tns., and *Phorocera erecta* Coq. No other parasites were bred from *P. nubilalis* larvæ.

In each of the species noted above the parasite larva emerged from its host larva just previous to normal pupation of the latter. All of these records were secured from host larvæ collected in the field and kept under observation in cages. During the progress of dissecting infested plants in the field, occasional parasitic dipterous larvæ and puparia were found in the tunnels of *P. nubilalis.* In these instances it was not possible to state definitely whether the parasite had emerged from *P. nubilalis,* or from some other larva which had wandered into the *P. nubilalis* tunnels.

For this reason these records are not included among the list of *P. nubilalis* parasites.

Only a small per cent of *P. nubilalis* larvæ were parasitized. During the entire season of 1918 a total of about twenty individual dipterous (Tachinid) parasites were bred, although several hundred larvæ were under observation in life-history cages and in the process of securing other biological data. The highest percentage of parasitism recorded was from a collection of 50 full-grown *P. nubilalis* larvæ dissected from the stalks in a badly infested field in Revere, Mass., on Aug. 23, 1918. Two parasitic larvæ emerged from the total of 50 *P. nubilalis* larvæ, a percentage of parasitism of 4.

A fact worthy of recording here is that during July, 1918, the larvæ of *Papaipema nitela* Gn. were very highly parasitized by *Masicera myoidea* Desv. The larvæ of *P. nitela* were tunneling through the same plant, or plants in the same hill, as larvæ of *P. nubilalis,* and the latter were only parasitized to a very small extent by the Tachinid. The statement has been made by foreign observers that one reason for the dearth of larval parasitism in *P. nubilalis* is their protected mode of living within the plant, but in the instance recorded it would seem as though *P. nubilalis* should have been parasitized to as great an extent as *P. nitela,* which at this time was following the same mode of attacking its host plant.

Parasites of the Pupa.

In Massachusetts two different species of hymenopterous parasites have been bred from pupæ of the European corn borer. These were determined by Mr. A. B. Gahan of the United States National Museum as (*Pimpla*) *Epiurus pterophori* Ashm., and (*Ichneumon*) *Amblyteles brevicinctor* Say.

The hymenopterous larva of *E. pterophori* was found feeding on the internal juices of a *P. nubilalis* pupa which had been broken open. The full-grown parasite larva spun a brown silken cocoon and pupated within the remains of its host. Only two of these parasites were bred.

The adult parasite *A. brevicinctor* emerged from the fully formed pupa of *P. nubilalis.* Two of these parasites were bred during August, 1918.

No other definite records of pupal parasitism were secured, although several hundred pupæ were under observation in life-history cages and during the progress of securing other biological data.

A single adult specimen of *Agrypon* sp. (det. Gahan) was found in a pasteboard box cage which contained about a dozen discarded *P. nubilalis* pupæ. The head cap of one of these had been forced off, so it is probable that the parasite emerged from this pupa. This cannot be considered a definite record of *P. nubilalis* parasitism, however.

A single specimen of *Macrocentrus* sp. (det. Gahan) was bred from a hymenopterous cocoon found in the tunnels of *P. nubilalis,* near the remains of a *P. nubilalis* pupa; but this also cannot be considered a definite record of *P. nubilalis* parasitism.

Summarizing the records of parasites bred from the European corn borer it will be noted that there are four species of Diptera and two species of Hymenoptera represented. The number of different species attacking *P. nubilalis* suggests the possibility that parasites may in the future have some influence in controlling the pest, but at the present time they cannot be relied upon to accomplish much.

PREDATORS.

BIRDS.

Several species of birds, including woodpeckers, blackbirds and crows, have been observed to feed upon the larvæ and pupæ of the European corn borer. Blackbirds have been observed to pick them out of infested corn tassel-stalks, frequently breaking over the tassel-stalk to reach the insect within. On one occasion a flock of crows settled down in an infested patch of field corn and devoured nearly all of the *P. nubilalis* larvæ which were feeding on the ears. Incidentally they also devoured some of the corn.

INSECTS.

Larvæ of the corn ear worm *Chloridea obsoleta* Fab. frequently kill and feed upon *P. nubilalis* larvæ which are feeding on the same ear of corn.

A small beetle, *Ips fasciatus*, is frequently found in *P. nubilalis* tunnels but has not been observed to prey upon the larva of the pest.

CONTROL.

DESTROYING PLANTS CONTAINING OVERWINTERING LARVÆ.

Bearing in mind the life history and habits of the European corn borer, it is evident that any measures for controlling the insect must be preventive rather than remedial. The most obvious method of preventing damage by the insect, or at least greatly reducing its numbers, is by the destruction of plants containing the overwintering larvæ. This may be accomplished any time during the period from the middle of October until the middle of the following May.

Burning Infested Plants.

Burning infested plants is undoubtedly the most practical and effective measure that can be adopted for the destruction of the overwintering larvæ. At first thought this seems to be an easy method of handling the problem, but when the great variety of food plants is considered, and also the extent of the infested area (320 square miles), it becomes one of great proportions. In order to destroy the larvæ in any given area by this method, all parts of the different food plants within that area must be burned, including the roots or stubble of the plants.

In comparatively large areas occupied by weeds this result may be accomplished by a running fire which, under favorable conditions, will effectively burn all plants to the surface of the ground, and kill any larvæ that may be present in the roots.

In the infinite number of small areas present throughout the infested region, and especially in the vicinity of buildings, it is not generally possible to start or maintain a running fire, and, under these circumstances, it becomes necessary to remove the infested plants and burn them in piles or in some receptacle provided for the purpose. This method entails considerable labor and expense, and when applied to the 320 square miles infested, presents a large problem.

Cornstalks and other infested plants in cultivated areas may generally be cut very close to the ground and burned in piles. The stubble may then be plowed out, raked up and burned, if no better means for its destruction are available. In small areas of corn it is sometimes more practicable to pull up and burn the entire plant than to remove and destroy the stubble.

During the early fall of 1918 considerable difficulty was experienced in attempting to burn cornstalks and other infested plants, owing to the large amount of water still present in the stalks, some of these plants being still green in appearance and resisting all efforts to burn them, even when kerosene oil was applied. It is possible, therefore, that in some instances infested plants must be burned during the early spring or during mild periods of the winter. It is not necessary to entirely consume the infested plants in order to kill the larvæ contained therein, but these plants should at least be given a thorough scorching or be exposed to considerable heat.

While experimenting with methods for burning infested plants several different types of torches were used. None of these, however, gave any satisfaction during the fall of 1918. This result may have been due to the green condition of many infested plants on which the torches were used, and it is possible that this method may give better results during the winter and spring, when the infested plants are dead and dry.

It is hoped that ultimately some type of a portable burning apparatus will be developed for use in burning large quantities of infested plants easily and at a low cost.

Any method adopted for the burning of infested plants throughout the entire infested area will result in a considerable outlay of money. Nevertheless, it is believed that burning is the best method to use in clean-up operations. Figures, compiled from data concerning the towns in the area infested by the pest up to November, 1918, show that about 50,000 acres must be treated.

Burying Infested Plants.

Burying infested plants may destroy the contained larvæ under some conditions. This method of eliminating infested material is especially desirable from an agricultural viewpoint, because the decaying plants provide humus so necessary to the maintenance of fertility and texture in the soil. If this method is adopted, however, the infested plants must be buried at least a foot in the soil, and the surface packed, if possible. Experiments to date have indicated that this method of destroying infested plants cannot be relied upon unless undertaken with great care.

In ordinary plowing operations infested plants are only partially turned under, and much of the plant remains are left on the surface of the ground. This is not an effective method for destroying infested plants.

During the month of May, 1918, infested cornstalks were buried in the soil to a depth of 6 inches, and in a manner resembling the work of an ordinary plow. The second generation larvæ contained in these buried stalks promptly made their way to the surface of the soil and entered plant remnants in the vicinity. Different results might possibly have been secured if the infested stalks had been buried in the fall and left in the soil through the winter, and experiments were started during the fall of 1918 to determine this point.

Infested cornstalks, buried to a depth of 12 inches in October, 1918, were dug up five weeks later and found to contain living larvæ. These were still actively feeding, although the interior of each cornstalk was soft and had begun to decay.

If a method could be developed for plowing under infested plants in order to destroy the larvæ contained therein it would be very desirable but in the present state of our knowledge concerning the matter this practice cannot be recommended.

Feeding of Infested Plants.

The feeding of infested plants to live stock is, from the economic viewpoint, the best possible means for destroying the larvæ of the European corn borer. The value of the stalks for fodder is not materially affected by the presence of the insects, and, if properly carried out, this method must result in the destruction of all insects within the infested plants. This is particularly true in the instance of infested corn fodder.

Shredding the corn fodder, or cutting it into small sections before feeding, greatly reduces the chance that any of the contained larvæ will survive. Live stock relish corn fodder when fed in this form, and will eat all parts of the plant.

Ensilage, by ordinary methods, effectively destroys all larvæ within the fodder, as the insects cannot survive the conditions existing in the silo.

Composting Infested Plants.

Whenever infested plants or parts of plants are placed in a compost or manure pile and covered deeply, the resulting decay and fermentation quickly result in the death of the larvæ contained within the plants.

It is a common practice on some farms to use corn fodder for bedding. This corn fodder ultimately becomes mixed with the manure, and any larvæ present in the corn fodder do not survive the treatment.

Application of Arsenicals to Plants.

Although much of the literature dealing with the habits of the European corn borer emphasizes the fact that the larva feeds entirely within the plant, close observation of the habits of the insect has shown that a large proportion of the first and second instar larvæ feed almost exclusively on the upper and lower leaf epidermis of some of their host plants. This circumstance at once suggests the possibility of control by the application of arsenical poisons, and experiments were attempted during the summer of 1918 in order to determine this point.

Dusting with Lead Arsenate.

An application of powdered lead arsenate was made on June 24, 1918, to 60 hills of sweet corn growing in the experimental plot at West Medford, Mass. At this time most of the corn borer larvæ were feeding on the leaf epidermis or on the staminate flowers of the tassel. An attempt was made to get the poison into the unfolding tassel and around the bases of the corn blades, as well as to cover the surface of the leaf blades. This treatment did not noticeably curtail the activities of the larvæ. When the ears developed they were infested in the same proportion as the check rows.

Other Dusting Experiments.

Calcium arsenate powder and equal parts of calcium arsenate powder and hydrated lime were applied in the same manner as arsenate of lead. The results were the same, although calcium arsenate appeared to be more effective than any of the other arsenical powders used. The check rows used in the calcium arsenate experiment were noticeably infested to a greater degree than the treated row. All the ears in the treated row were at least somewhat infested, however.

Spraying with Lead Arsenate.

Three applications of lead arsenate, at the rate of 1 ounce of the powder in 2 gallons of water, were made to 32 hills of sweet corn on Aug. 5, 13 and 22, 1918. Daily observations were made of these corn plants, and an effort was made to apply the poison at a time when it would be most effective in covering the surface areas of the plant that was being eaten by the larvæ of the borer.

At the time of application the poison spray adhered to the foliage very well, and the excess liquid ran down the leaf blades and collected at the bases of the tassels and leaf blades, these points being the favorite feeding places of the young larvæ.

When the ears developed in this plot a close examination showed that 211 ears were present, of which the entire number were infested. Many of these ears were only damaged to a slight degree, however, and in general were in a much better condition than those in the check rows.

About 52 per cent of the tassels were broken over in the sprayed plot while 61 per cent were broken over in the check rows.

The stalks of the sprayed plants were all infested by the pest, but surface feeding had been entirely prevented. The sprayed plants had a much better (greener) color than the plants in the check rows. Late in October most of the plants in the check rows had fallen over as a result of *P. nubilalis* attack, but only about 10 per cent of the sprayed plants had done this.

The results of this experiment indicate that many of the European corn borer larvæ can be killed by the application of arsenicals at the right time, but that the damage to the plants by the insect cannot be prevented to a paying degree.

Corn grows very rapidly throughout the period when spraying is necessary, and the newly developed portions of the plant are the favorite points of attack, viz., bases of the leaf sheath, surface of the leaf blade, and the tassel. This necessitates frequent sprayings in order to combat the larvæ of the pest, which hatch over quite an extended period of time. The cost of spraying large areas would, therefore, be probably prohibitive.

Spraying with Calcium Arsenate.

Three applications of calcium arsenate, at the rate of one-half ounce of the powder to 2 gallons of water, were made on the same date and in the same manner as have been detailed for lead arsenate. The results were practically the same, although calcium arsenate appeared to be more satisfactory in its prevention of injury than did lead arsenate.

Cultural Practices to avoid Damage.

Several observations made during the summer of 1918 seemed to suggest the possibility that damage by the borer could be avoided by regulating the time of planting corn so that the plants would not be at a stage to attract the female moths of the insect during their time of activity. The female moths prefer to deposit their eggs upon some plant bearing a soft, green seed head. If corn plants bearing a tassel are not available the females habitually deposit their eggs upon some other species of host plant that bears a seed head in the desired stage of development.

It was observed that adjoining corn fields, in different stages of development, were often infested in varying degrees by the insect. In one market garden at West Medford, Mass., a field of sweet corn, planted on April 1, 1918, was very severely infested by the borer. An adjoining field of sweet corn, planted about April 10, 1918, was only infested to a moderate degree. A third field of sweet corn, planted about April 30, 1918, was practically free from the pest, and an examination of the ears when harvested showed only a very small per cent of injury.

OTHER INSECTS FREQUENTLY MISTAKEN FOR THE EUROPEAN CORN BORER.

THE STALK BORER.

The stalk borer *Papaipema nitela* Gn. is frequently mistaken for the European corn borer. *P. nitela* attacks and tunnels in the stalks of a great variety of plants, including corn, tomatoes, potatoes and many other wild and cultivated plants. During the spring and early summer the larva is quite commonly found in the same field and often in the same plant with the European corn borer, but it may be distinguished from the latter during its early stages by the presence of a wide transverse brown band extending around the middle of the body. When nearly full grown the *P. nitela* larva more closely resembles *P. nubilalis*, but may be easily distinguished from the latter at that time by the absence of the short stout spines which arise from the light-colored abdominal areas of *P. nubilalis*, and by the uniformly greater length and breadth of the *P. nitela* larva. Another point of difference between the two species is that *P. nubilalis* pupates within its larval tunnels, while *P. nitela* leaves its host, when full grown, and pupates in the soil. In corn the larval tunnels of the two species are quite often similar, but the tunnels of *P. nubilalis* are generally packed with a light colored frass, and in some instances contain the empty pupal skin, while the larval tunnels of *P. nitela* are generally free from frass, or, if present, the frass is much darker and composed of larger particles than that of *P. nubilalis*.

Many reports of *P. nubilalis* injury have been found, upon investigation, to have for their basis the injury caused by *P. nitela*.

THE CORN EAR WORM.

Larvæ of the corn ear worm *Chloridea obsoleta* Fab. are sometimes mistaken for those of the European corn borer. The larvæ of the first-named species are frequently found feeding on the same ear of corn with larvæ of *P. nubilalis*, but may be easily distinguished from the latter by the presence of varicolored stripes running lengthwise of the body, and by the fact that larvæ of the corn ear worm, as the name implies, confine their operations, when feeding on corn, almost exclusively to the kernels of the ear, and do not enter the cob or the stalk. They may generally be found feeding on the surface of immature ears.

CUTWORMS.

Several species of cutworms are occasionally found feeding on the ears of corn, but may be distinguished from larvæ of the European corn borer by the same characteristics as have been mentioned in the instance of the corn ear worm.

SUMMARY.

The European corn borer has recently become established in the eastern part of Massachusetts. This pest has long been recorded in Europe and Asia as one of the most serious insect enemies of corn, hemp, millet, hops and other crops. It was probably introduced into Massachusetts through the importation from Europe of raw hemp for use in cordage factories, about the year 1910.

The insect was first discovered in Massachusetts in the summer of 1917. At that time it was causing severe damage to sweet corn and other plants. Preliminary investigations indicated that the insect had become established over an area of about 100 square miles immediately north and northeast of the city of Boston, and that the serious nature of the pest called for prompt and vigorous action by both State and Federal authorities if the corn crop of the country was to be safeguarded.

During the season of 1918 the Massachusetts Agricultural Experiment Station and the United States Bureau of Entomology co-operated in a further investigation of the insect, in order to obtain detailed information concerning its distribution, habits and food plants, with a view to instituting quarantine and control measures that would confine the pest to its present area and lead to its ultimate control.

As a result of these investigations it was determined that up to November, 1918, the European corn borer had established itself in an area of about 320 square miles, comprising 34 towns, located immediately west, north and northwest of the city of Boston.

The insect attacks a great variety of both wild and cultivated plants, including sweet corn, field corn, fodder corn, timothy, oats, celery, tomatoes, potatoes, beans, beets, Swiss chard, chrysanthemums, dahlias, gladioli and many of the larger weeds and grasses.

Corn is its favorite food plant, however, and is injured by the pest to a greater extent than any of its other host plants. All parts of the corn plant are attacked, except the fibrous roots. The economic injury to corn consists of the following: (1) injury to tassel which results in poor fertilization; (2) injury to stalk which reduces vitality of plant; (3) injury to stalk which causes breaking over of plant; (4) injury to stalk which indirectly affects the ear by cutting off its supply of nutriment; (5) injury to ear which directly affects the yield; (6) injury to the silk of the ear which results in poor fertilization.

A maximum of 117 full-grown European corn borer larvæ have been taken from one corn plant and 311 full-grown larvæ were dissected from a single hill of corn containing four plants. The average number of larvæ dissected from 75 corn plants, taken at random in the same field, was 46. This is at the rate of 1,050,640 larvæ per acre of corn. As many as 15 were found attacking a single ear of sweet corn.

Field counts made in infested corn fields showed that frequently as high as 100 per cent of the ears were infested.

The other economic plants mentioned as hosts of the European corn borer are attacked by the insect only in the absence of corn, or as a result of their nearness to corn in badly infested fields.

The wild plants mentioned as hosts of the insects are attacked only in the absence of corn, and are not economically important except that they serve as intermediate hosts for the multiplication of the pest.

There are two generations of the insect each year. The nearly full-grown second generation larvæ pass the winter in a dormant condition within their tunnels, and resume feeding with the approach of warm weather in the spring. They pupate about the middle of May. The pupal period lasts about seventeen days, and the moths emerge the first week of June to deposit eggs for the first generation. A maximum number of 727 eggs was deposited by a single second generation female in life-history cages, and the average number deposited by a single female was 337 eggs. These eggs are deposited in masses from 5 to about 50 eggs, on the under sides of the leaves of the host plant. The first generation larvæ hatch in about seven days and reach their full growth in about forty-four days. They pupate within their larval tunnels, and the pupal period lasts about nine days. The moths emerge about the middle of July and deposit eggs for the second generation. A maximum number of 903 eggs was deposited by a single first generation female in life-history cages, with an average number per female of 545 eggs. The second generation larvæ hatch in about six days and are nearly full grown by winter.

Four species of dipterous parasites were bred from the larvæ of the European corn borer, and two species of hymenopterous parasites were bred from the pupæ. No parasites were bred from the egg. The percentage of parasitism by any of these species is very small, and at the present time they cannot be relied upon to hold the pest in check.

Burning the plants containing the overwintering larvæ, any time during the period from the middle of October to the middle of the next May, is the most effective control method now known. Other methods, applicable under certain conditions, for destroying infested plants are placing in manure or compost; in a silo; burying deeply in the soil; or feeding directly to live stock, preferably shredded or chopped finely. Spraying infested corn plants with arsenicals in order to kill the young larvæ feeding on the surface of the plant was not found to be practical, owing to the number of sprayings necessary to keep the growing plant covered with the arsenical, and to the fact that the small per cent of larvæ not killed by the arsenical was sufficient to generally ruin the ears of corn for commercial purposes. Cultural practices may aid in avoiding damage by timing the planting of corn in such a manner that the plants may not be at a stage of growth which attracts the female moths during their period of oviposition. The female moths prefer to deposit their eggs upon some plant bearing a soft green seed head. If corn plants bearing a tassel are not available the females habitually deposit their eggs upon some other kind of host plant.

In October, 1918, a Federal quarantine was established prohibiting the interstate movement of corn fodder, cornstalks, green sweet corn, roasting ears, corn on the cob and corn cobs from the towns known to be infested by the European corn borer.

In August, 1918, the State of Vermont issued a quarantine order prohibiting the movement of all stalks or ears of the corn plant, either green or dried, from the State of Massachusetts into the State of Vermont. A similar quarantine has been established by Connecticut.

During the spring of 1918 a campaign was inaugurated by the Massachusetts State Board of Agriculture for the destruction of all infested plants within the infested area. This resulted in greatly curtailing the activities of the insect during the following season. In October, 1918, this campaign was resumed under the joint auspices of the Massachusetts State Department of Agriculture and the United States Bureau of Entomology, Division of Cereal and Forage Insect Investigations.

Owing to the open winter of 1918–19 a continuation of the clean-up work was possible to a greater extent than was expected. This, after Dec. 1, 1918, was done mainly with funds provided by the United States Bureau of Entomology.

Since the preparation of this bulletin the European corn borer has been found over an area of about 400 square miles near Schenectady, N. Y.

To avoid any possible confusion as to responsibility for the material contained in this bulletin, it should be stated that the sections on Geographical Distribution, Quarantine Measures, Insects frequently mistaken for the Corn Borer, the Introduction, and the Summary were supplied by Mr. Caffrey. The observations under the heads of History in the United States, Food Plants, Life History, Habits, and the others were made by Mr. Vinal; the descriptions of the different stages were the result of examination of specimens by Messrs. Vinal, Caffrey and Fernald.

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EXPLANATION OF PLATES.

All except Figs. 12, 13 and 14 drawn from sketches by R. E. Snodgrass.

PLATE I.

Fig. 1. — First larval instar.
Fig. 2. — Second larval instar.
Fig. 3. — Prothoracic shield of first two instars.
Fig. 4. — Third larval instar.
Fig. 5. — Prothoracic shield of third instar; spines not shown.
Fig. 6. — Fourth larval instar.
Fig. 7. — Prothoracic shield of fourth instar; spines not shown.

PLATE II.

Fig. 8. — Fifth larval instar.
Fig. 9. — Prothoracic shield of fifth instar.
Fig. 10. — Sixth larval instar.
Fig. 11. — Prothoracic shield of sixth instar.
Fig. 12. — Venation of fore wing of adult.
Fig. 13. — Venation of hind wing of adult male.
Fig. 14. — Frenulum of hind wing of female.

PLATE I.

Fig. 1

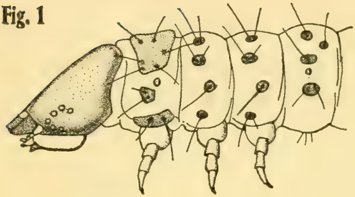


Fig. 3

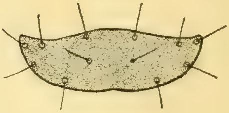


Fig. 2

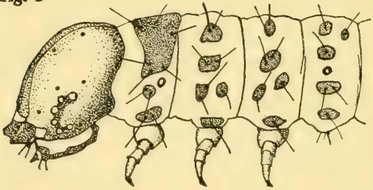


Fig. 4

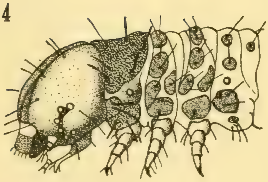
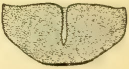


Fig. 5



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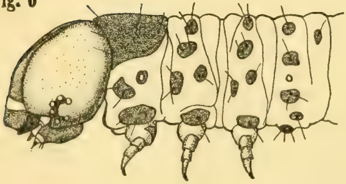

Fig. 7

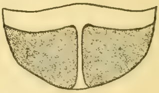

PLATE II.

Fig. 8

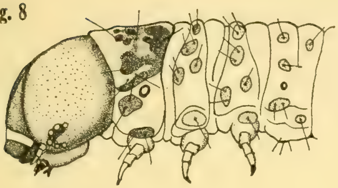

Fig. 9

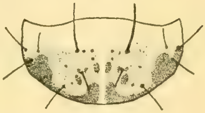

Fig. 10

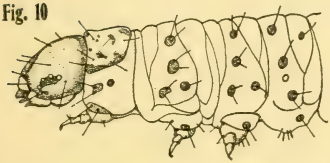

Fig. 11

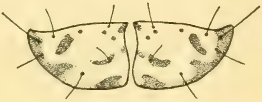

Fig. 12

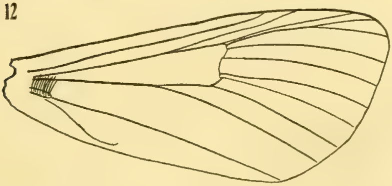

Fig. 13

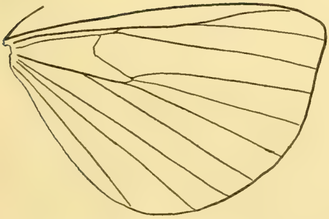

Fig. 14

BULLETIN No. 190 SEPTEMBER, 1919

MASSACHUSETTS
AGRICULTURAL EXPERIMENT STATION

THE PROPAGATION OF APPLE TREES ON THEIR OWN ROOTS

By J. K. SHAW

Requests for bulletins should be addressed to the
AGRICULTURAL EXPERIMENT STATION
AMHERST, MASS.

Publication of this Document
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Supervisor of Administration.

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BULLETIN No. 190.

DEPARTMENT OF HORTICULTURE.

THE PROPAGATION OF APPLE TREES ON THEIR OWN ROOTS.

BY J. K. SHAW.

INTRODUCTION.

The methods of propagation of tree fruits in common use among nurserymen produce trees the trunk and crown of which are of the variety desired, while a part or the whole of the root system is of seedling origin. In many cases roots are thrown out from the base of the scion that are, of course, of the variety of the aerial part of the tree, but it is doubtless true that in most cases, especially with budded trees, the seedling forms the greater part, if not the whole, of the root system. This means that in any orchard of any one variety there is a great deal of variation in the root systems. No two are of identical constitution. This is due to the complexity of the genetic constitution of our cultivated varieties of apples. Seedlings of a single variety, even if from self-fertilized seed, show great variation and many different combinations of characters.

It is reasonable to suppose that these differing seedling roots should cause more or less modification of the top, and there is abundant evidence that this is the case. The most common example is found in dwarf trees. There are many types of the common apple that, when used as stocks, inhibit the growth of the scion, and those that will throw out roots from the stem readily are used as dwarfing stocks. It is well known that dwarf stocks influence also the size, color, quality and season of maturity of the fruit. It is therefore reasonable to believe that many of the individual differences among the trees in an orchard may be due to the varying seedling root systems, and such individual differences, especially in productiveness, are greater than is generally realized. If trees could be propagated on their own roots, or on the roots of a clonal variety known to be well suited to the scion variety, much might be gained in uniformity and fruitfulness in the orchard.

Another advantage in having trees grafted on roots of known varieties lies in the greater resistance to insects and diseases of the roots that can be secured in this way. This idea is in practical use in Australia and South Africa, where the method is used to avoid serious trouble with the root form of the woolly aphis. This insect was early imported from America, and is there known as the American blight. It was found that Northern Spy roots were highly resistant to this insect, and it is now the usual practice in those countries to propagate all varieties on roots of the Northern Spy, or some other resistant variety.[1]

It has been the observation of the writer that roots of different varieties differ in their susceptibility to crown gall, and it is reasonable to suppose that the same may be true with other root diseases. Root troubles are the cause of failure of bearing trees more often than is generally realized. Propagating varieties on known roots offers a chance of overcoming, to a considerable degree, at least, many of these root troubles.

In the northern part of the apple belt, especially in the prairie northwest, resistance of the roots to extreme cold becomes important, and it is considered highly desirable to get varieties on their own roots in order to avoid root killing in winter, when the temperature of the soil falls to an extremely low point. If trees of the varieties suited to these conditions could be worked on roots known to be of extreme hardiness, it would contribute to the longevity and consequent fruitfulness of the orchards.

If we concede that trees growing on roots of known varieties, either as own-rooted trees or trees on roots of other known varieties, may be more desirable for orchard purposes than trees on miscellaneous unknown seedling roots, there are suggested many problems for investigation. For example, what varieties on their own roots are resistant to the various insects and diseases, and what ones possess extreme hardiness to severe cold? What is the effect of different varieties used as root systems on the growth and fruitfulness of the scion variety?

Before these problems can be solved it is necessary to propagate trees on their own roots. The general question of the interrelation of stock and scion is under investigation at this station, and it is the purpose of this paper to set forth some of the results obtained in propagating trees on the roots of known varieties.

The first step in securing trees on known roots is to induce the formation of roots from the stem of the chosen variety. The methods most used in practice are by cuttings and by layers. It is known that apple wood roots from cuttings with the greatest difficulty, and that only certain varieties root readily by the somewhat slow and cumbersome method of layers. The method of growing trees on Northern Spy roots to secure resistance to the woolly aphis may be termed the nurse-root method. In this method a rather long scion is grafted by any appropriate method on a short piece of seedling root, and planted out in the usual way. Roots arise from the Spy scion, and the seedling nurse root may be removed, leaving the tree on its own roots.

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[1] Cole, C. F.: Jour. Agr. Victoria, 9: 338 (1911).

PROPAGATION BY CUTTINGS.

There are few published records of attempts to propagate apple trees by cuttings. Doubtless many have been made and not reported, for the uniform results on record may be described in the single word — failure.

Luke [1] attempted to root apple cuttings of various sizes and lengths at cutting-bed temperatures of 64° and 67°. All failed to strike root. Luke was able to induce root cuttings to grow with fairly good success.

Attempts to root apple cuttings were made during the summer of 1912. Green wood cuttings 3 to 4 inches long were made in early August and September, and set in sand in the greenhouse. Powdered charcoal was also used as a propagating medium, both alone and as a one-half inch layer over sand, with the hope that it might check disease. Bottom heat in varying degrees was used in some cases, also an enclosed propagating frame. In short, an effort was made to provide the best possible conditions for cuttings. Something over a thousand cuttings of several different varieties were made. The results were much the same in all cases. The cuttings formed a callus, varying somewhat with the variety, and the buds started out until the leaves were about one-fourth inch long. This occupied about two weeks, after which growth ceased. The final result was the same in practically all cases. Of the 1,000 or more cuttings only a single one of the Fall Pippin variety rooted, and that only a single short shoot that was broken off in removing from the sand, so that it failed to grow. Fig. 1 is a typical representation of the range of development of callus and leaf. Arranged in order of callus development the varieties are Yellow Transparent, Fall Pippin, Red Astrachan, Bough (Sweet), Ben Davis, Wagener. As will be shown later, these varieties may be induced to root from the scion, when grown by the nurse-root method, more or less readily, according to the variety. There is, however, little or no correlation between callus growth and root formation, as may be seen by comparison with the numbers rooting shown in Table 2.

One lot of cuttings was watered with a nutrient solution, using a formula in common use for growing seedlings. The only effect was a noticeable growth of green algæ over the surface of the sand. The cutting growth was hindered rather than helped.

In spite of these failures it is the opinion of the writer that it is possible to grow apple trees from cuttings. To an inquiry addressed to many of the leading nurserymen of the country, thirty-five replied that they had never seen cuttings or prunings from the trees taking root, while seventeen professed to have observed such an occurrence, though none of them considered it at all common. One nurseryman reported having planted well-callused scions in a mixture of sand and soil, and that "the best stand we ever had was something less than 10 per cent of the cuttings planted." The trees were weak for a year or two. The late T. V. Munson of Denison, Tex., says: "I have often had apple and even peach switches cut from the trees in February and stuck into the ground (very sandy) for label sticks, take root and grow off well."

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[1] Luke, F. K.: Proc. Columbus Hort. Soc., XIII: 95 (1898).

In the spring of 1913 a considerable number of root cuttings from young trees were planted in the nursery row. No record was kept of them, but they made a good stand though growth was very slow the first season. It is the practice of at least one nursery firm to dig trees already established on their own roots once in two years and cut off the roots for propagation by root cuttings. The trees are then replanted and a new crop of roots grown.

In a later experience of the writer, root cuttings from the root system of bearing trees were used in an attempt to propagate the stock variety. This resulted in almost a complete failure. The roots used were from one-quarter to one-half inch in diameter, and when planted in the open, about 3 inches long. Others planted in the greenhouse were about 1½ inches long. Whether older roots propagate with greater difficulty, or whether some unfavorable conditions not readily seen interfered with success, cannot be told with certainty.

PROPAGATION BY LAYERS.

The method commonly used in propagating dwarf trees is by some form of layerage. A considerable number of attempts were made to induce root formation by air layerage. Earthen pots were split, and in early August were placed in appropriate position on growing shoots and filled with sphagnum moss. They were kept moist by frequent watering. None of these air layers showed root formation. It proved difficult with the rather small pots used to maintain uniform moisture conditions, and this may have had something to do with the failure.

In the spring of 1917 two-year-old trees growing in the nursery row were cut off 3 or 4 inches above the ground and allowed to stool. Later in the summer soil was heaped up around the new shoots to the height of 4 or 5 inches. The varieties used were Ben Davis, Bough, Rhode Island Greening and Transcendent. None of these shoots have been separated in an attempt to establish them as independent trees, but investigation in the spring of 1919 showed that most shoots of all these varieties bore small roots, coming out near the junction with the cut-off stump.

PROPAGATION BY THE NURSE-ROOT METHOD.

It is well known to most nurserymen that root-grafted trees often send out roots from the scion, and may eventually become established, partially, at least, on their own roots. In an attempt to collect information a questionnaire was sent to the leading nurserymen. About 75 replies were received, and most of these show care and thought in answering the questions. They were suggestive at the outset of this work, and are interesting to review after eight years' work on the problem. The first question was, "Have you ever observed root-grafted apple trees rooting from the scion?" Fifty replies say yes, and 6 reply no. Especially in the Middle West nurserymen regard it as a common or usual thing, while in the East, South and on the Pacific coast it seems rather less well known. It may be that rooting is more frequent in the rich, loamy soil of the Middle West, or it may be that it is because the practice of root grafting prevails there more than in the eastern and other nursery regions.

The second question asked, "In what varieties, and in about what proportion of the trees," rooting from the scion had been observed to occur. The general trend of the replies was that all varieties might do so, Winesap being the only sort mentioned as not rooting. Generally the varieties mentioned were those most extensively grown. Ideas as to proportion of trees rooting were diverse, some saying a small percentage and others nearly all.

A question as to the most favorable conditions for rooting brought in nearly every case, when a positive reply was made, the suggestion of the long-scion, short-root graft; deep planting was often suggested; abundant fertility and plenty of moisture were often mentioned; where soil preference was expressed it was for a sandy or loamy soil.

Methods used.

The first lots of grafts for the purpose of securing trees on known roots were made in 1912, and others were made during subsequent years, including 1917. The method has been to make an ordinary piece root, whip graft, using a straight root 2 to 3 inches long, and a scion 6 to 8 inches long. The grafts have been made at various times in the late winter and early spring, most of them in February or early March. For the most part they have been made by student amateurs, and yet they have been as well made as the average of commercial work. It has appeared that there is more dependent on the way the scions were handled before and after grafting than in the skill with which the union was made. To test the necessity for large contact of the cambium layers five different methods or degrees of matching were tested, as follows: —

(*a*) Matched on one side only, not at top or bottom.
(*b*) Matched on both sides, not at top or bottom.
(*c*) Matched at top, not at sides or bottom.
(*d*) Matched at bottom, not at sides or top.
(*e*) Perfectly matched all around.

The variety used was Baldwin.

Where it was desired to avoid matching, the scion or root was cut away, if necessary, to make a space of at least 1 millimeter. The grafts were then planted and cared for in the usual way. The results are shown in Table 1.

TABLE 1. — *Results of Various Methods of matching Cambium.*

	Number planted.	Per Cent growing.	Per Cent rooting from Scion.	Average Height of One-year Whips (Feet).
(*a*) Matched on one side,	45	80	8	3.2
(*b*) Matched on both sides,	44	65	24	4.1
(*c*) Matched at top,	45	42	39	3.8
(*d*) Matched at bottom,	45	66	19	3.0
(*e*) Matched all around,	45	60	36	3.4

These figures show no very consistent results. Evidently so far as the development of nursery trees is concerned, a small contact of the cambium layers is as good as a perfect fit. Nevertheless, it is quite possible that more extensive tests might reveal significant results.

In several cases grafts have been made in April and set immediately in the nursery row. Such lots have been somewhat slow in starting, but have given fully as good stands as those that had been stored for two months or more. Probably due in part, at least, to the slow start, they have made somewhat smaller trees at the end of one or two seasons' growth.

In some cases, storage has been in boxes packed in moss or other moisture-holding material. Sometimes this has seemed to be injurious, perhaps through the displacement of oxygen by carbon dioxide, and the grafts have failed to give a good stand, though starting well for the first week or ten days.

The planting has been done with a double or triple dibber made out of gas pipe or steel tubing. These tools enable one to plant the graft deep in the ground with only one or two buds showing. The earth has been pressed close to the graft by thrusting down a straight spade close to the graft, and tramping solidly with the feet.

In all cases the trees have been allowed to grow for two seasons. They make a small growth the first season, probably largely because of the small size of the nurse root. In most cases they have been cut back to the ground at the beginning of the second season, after which they make fairly strong one-year whips. Many of the trees have been budded the first summer, so that if they rooted from the scion we would have at the end of the second season the desired variety established on the root system of a named variety; for example, a Baldwin top on a Ben Davis root system. This method saves time, but owing to uncertainty of rooting from the scion it is not very satisfactory. When the trees are dug a record is made of those rooting and not rooting from the scion, and from the former the seedling root is cut. The point of union is always clearly seen, and the only time a question arises is when a root appears just at the line of union. As a matter of safety in the main investigation, such trees have been counted as not rooted. After cutting away the seedling root the trees are replanted and budded during the summer if desired, and if they have not been already. At the end of one or two years we have a satisfactory tree established on its own roots or the roots of another named variety.

Relation of the Variety to Root Formation.

At the start of this work the sole purpose was to obtain trees on known roots for purposes of orchard and laboratory investigation of the interrelation of root and scion. It soon became evident that there were great varietal differences in the readiness with which roots were thrown out from the scion, and tests have been made of over 150 different varieties and species to measure their rooting ability. These tests have extended over a period of seven years. Some varieties have been tested only once, others two or more times, and some have been tested six times, and all in varying numbers, as shown in Table 2. Most of the scions have been taken from bearing trees or from those that have since come into bearing. A record has been kept of each lot separately, so that in a few cases, where the parent tree proved to be misnamed, the necessary correction has been simple. A few lots of scions were secured from nurseries; those were carefully examined for mixtures of varieties, and, so far as possible, compared with trees known to be true, and with printed descriptions. There is no more excuse for mixtures of trees in the nursery row than for mixtures of fruit in the barrel. All cases of doubtful identity have been thrown out, and it is thought that there is little chance of error in the varieties given in the table.

Individual lots of the same variety have differed widely in the percentage rooting, internal conditions in the scion or environmental conditions, or both, evidently playing an important rôle in root formation. Some of these will be discussed later.

TABLE 2. — *Varietal Differences in Root Formation.*

VARIETY.	Number grown.	Per Cent rooting.	VARIETY.	Number grown.	Per Cent. rooting.
Akin,	85	27	Golden Russet,	36	28
Alexander,	48	21	Golden Sweet,	48	44
Anisim,	80	6	Gravenstein,	100	55
Arctic,	97	19	Grimes,	83	41
Arkansas,	35	77	Henry Clay,	193	43
Arkansas Black,	45	44	Hibernal,	34	61
Bailey Sweet,	108	95	Hibkee,	13	34
Baldwin,	898	32	Horse (Yellow Horse),	133	9
Ben Davis,	627	51	Hubbardston,	947	21
Bethel,	137	0	Huntsman,	82	23
Bismark,	73	31	Hurlbut,	170	7
Black Gilliflower,	34	6	Ingram,	261	2
Blenheim,	54	35	Isham Sweet,	81	2
Blue Pearmain,	82	24	Jacobs Sweet,	28	4
Bonum,	206	14	Jefferis,	278	3
Bough (Sweet),	552	98	Jewett,	580	20
Canada Baldwin,	36	53	Jonathan,	175	11
Charlamoff,	109	11	July, Fourth of,	55	62
Chenango,	89	69	Keswick,	121	56
Colorado Orange,	72	3	King David,	29	22
Cox Orange,	201	8	Kinnaird,	98	7
Deacon Jones,	7	57	Lady,	160	3
Delicious,	131	22	Lady Sweet,	75	8
Dominie,	59	55	Lawver,	21	71
Dudley (North Star),	17	70	Limber Twig,	83	73
Early Harvest,	46	72	Longfield,	67	39
Early Melon,	104	37	Lowland Raspberry,	55	78
Early Ripe,	58	29	Lowell,	90	8
Ensee,	162	6	Lowry,	260	13
Esopus Spitzenburg,	69	79	Magnate,	174	3
Fallawater,	15	67	Maiden Blush	42	67
Fall Pippin,	114	43	Malinda,	86	26
Fameuse,	56	80	Mann,	61	33
Gano,	51	63	McAffee,	22	27
Garden Royal,	22	50	McIntosh,	208	74
Gideon,	57	40	McMahon,	35	29

TABLE 2 — *Concluded.*

VARIETY.	Number grown.	Per Cent. rooting.	VARIETY.	Number grown.	Per Cent rooting.
Milding,	50	54	Scott Winter,	75	44
Milwaukee,	6	17	Shiawassee,	110	46
Minkler,	132	18	Silken Leaf,	10	40
Missouri Pippin,	99	41	Smith Cider,	167	14
Mother,	54	39	Smokehouse,	99	51
Newtown Pippin,	102	68	Stark,	47	43
Newtown Spitzenburg,	44	37	Stayman,	61	41
Northern Spy,	629	58	Stump,	81	30
Northwestern Greening,	107	64	Summer Rambo,	99	13
Oldenburg,	958	25	Sutton,	32	34
Ontario,	87	53	Swaar,	136	32
Opalescent,	97	89	Tolman,	1,450	3
Ortley,	110	2	Tetofski,	85	3
Palmer Greening,	141	46	Tompkins King,	198	62
Paradise Winter Sweet,	114	2	Transcendent (Crab),	462	45
Paragon,	100	60	Twenty Ounce,	102	38
Patten Greening,	98	8	Wagener,	676	45
Peck Pleasant,	180	34	Wallbridge,	111	20
Pewaukee,	30	57	Walter Pease,	57	4
Plumb Cider,	98	19	Wealthy,	781	25
Porter,	265	6	Westfield,	103	83
Primate,	138	92	White Pearmain,	91	14
Pumpkin Sweet,	220	12	Williams,	240	30
Rambo,	94	32	Willow,	17	24
Ralls,	32	41	Wilsons June,	67	60
Red Astrachan,	601	67	Windsor,	277	2
Red Bietigheimer,	102	46	Winesap,	200	34
Red Canada,	54	2	Winter Banana,	166	48
Red June,	298	27	Winterstein,	105	9
Red Russet,	12	45	Winter St. Lawrence,	27	21
Rhode Island Greening,	979	30	Wolf River,	75	71
Ribston Pippin,	72	9	Wismer,	56	13
Rome Beauty,	66	9	Yellow Belleflower,	125	3
Roman Stem,	43	70	Yellow Transparent,	1,077	26
Roxbury Russet,	252	13	York Imperial,	57	23
Salome,	43	63			

Grafts have been made of twelve varieties of Siberian crab apples, but only those of Transcendent are reported in this paper, owing to some uncertainty in the correctness of the variety names. However, it may be said that they show a range in rooting percentages from zero to 96 per cent, being in this respect like the varieties of the common apple.

Tests have been made of a number of forms of our native apples. The names under which they were received and the sources were as follows: —

Pyrus angustifolia,	Arnold Arboretum, Boston, Mass.
Pyrus coronarius,	Arnold Arboretum, Boston, Mass.
Pyrus coronarius,	Prof. W. H. Chandler, Ithaca, N. Y.
Malus coronarius,	John Dunbar, Rochester, N. Y.
Malus glaucescens,	John Dunbar, Rochester, N. Y.
Pyrus iowensis,	Prof. L. Green, Ames, Iowa.
Malus platycarpa,	Arnold Arboretum, Boston, Mass.
Pyrus iowensis,	D. S. Lake, Shenandoah, Iowa.
Soulard Crab,	Prof. L. Green, Ames, Iowa.

These were grafted and planted in the usual manner and dug after two seasons' growth. The numbers varied from 5 to 104 of each form. No tree in the entire collection showed any signs of throwing out roots from the scion.

Trees of certain varieties failing to root from the scion during the seasons of 1915–16 were replanted in the spring of 1917. They were moderately strong whips, and were planted about a foot deep so as to cover several inches of the stem. The purpose was to secure additional trees on known roots, and to see if such trees would root more or less freely than newly made grafts. The results are shown in Table 3. The first column gives the number of trees replanted, and the second column the per cent rooting from the scion. For purposes of comparison the per cent rooting from the first planting of these varieties is given in the third column. Only in the case of Northern Spy is the percentage materially lower in the reset trees than in newly planted grafts. In most cases there is a materially higher proportion rooting from the scion. The replanting was on the same plot of ground. The difference may be due to more favorable weather conditions or other environmental causes, but it seems reasonable to suppose that the larger, stronger trees were better able to throw out roots. As a practical means of getting trees on their own roots by the nurse-root method, it would seem wise to replant those failing to root on the first trial.

TABLE 3. — *Reset Trees rooting in 1917–18.*

	Number planted.	Per Cent rooting.	Per Cent rooting from First Planting.
Baldwin,	18	39	39
Ben Davis,	9	56	39
Hubbardston,	74	22	23
Jewett,	52	27	14
Northern Spy,	10	40	52
Oldenburg,	62	52	21
Red Astrachan,	26	65	63
Rhode Island Greening,	18	44	31
Tolman,	132	19	6
Transcendent,	68	72	36
Wagener,	44	68	32
Wealthy,	24	54	21
Yellow Transparent,	82	48	17

EFFECT OF SOIL AND SEASON.

These experiments have continued over a period of seven years, new plantings being made in all but the seventh year. The six plantings have been on different plots, but all are similar in soil texture. The first lot grafted in 1912 was planted in part on experiment station land, while part were planted in a commercial nursery in Westfield, Mass. Later plantings were all at the experiment station. The number grown and per cent rooted from the scion at Amherst and Westfield are given in Table 4. These figures show no very consistent differences between the two locations. Where there are wide differences, one is below and the other above the average for the variety. Small numbers involved will account for many of the divergences in the proportion rooting from the scion. The soil in the two locations is similar, the Westfield location having a little less gravel and more fine sand and silt. Both would be called fine sandy loams.

TABLE 4. — *Trees grown at Amherst and Westfield in 1912–13.*

	AMHERST.		WESTFIELD.	
	Number planted.	Per Cent rooting.	Number planted.	Per Cent rooting.
Baldwin,	28	14	68	16
Ben Davis,	18	83	82	37
Bough (Sweet),	10	100	130	100
Hubbardston,	21	10	138	16
Northern Spy,	10	100	118	36
Oldenburg,	21	43	111	43
Red Astrachan,	22	36	106	55
Rhode Island Greening,	25	16	108	20
Tolman,	14	0	86	0
Wagener,	33	45	19	39
Wealthy,	22	14	51	51
Yellow Transparent,	23	17	52	40

Certain varieties called for by the plan for this investigation of the interrelation of stock and scion have been planted in all or nearly all of the six lots grown during the period of this investigation. Table 5 shows the percentages rooting from the scion in these lots. There is considerable variation from year to year in the different varieties, due, probably, to a variety of causes. As has been stated, a part of Series 1 was grown in Westfield, Mass., and the rest at Amherst. Series 2 was grown in Amherst adjoining Series 1, and under very similar soil conditions. Series 4 was on another adjoining plot and similar to the others, except that it contained a considerable amount of land that was rather wet. This did not visibly affect the growth of the trees, but may have interfered with root formation. Another portion failed to give a good stand of trees. This was given some special investigation without bringing to light any satisfactory reason for the poor growth. Series 3, 5 and 6 were grown in another field on plots not far apart and on similar soils. Like the other plots these were a fine sandy loam. Series 6 was grown on a plot a considerable portion of which was rather poorly drained, which may have been the cause wholly, or in part, of the poor rooting from the scion. The stand was good and the trees all made a fair growth. Series 5 was grown on well-drained soil and made a good growth. It is difficult to say why the general average of rooting is so low.

In Series 1 the varieties showing low percentages of rooting are generally those maturing growth rather late, while the early maturing varieties, such as Jewett, Oldenburg, Wealthy and Yellow Transparent, rooted better than in most other years. If this is significant it may mean that the scion contained a greater supply of stored food, due to conditions the previous season rather than any conditions during the two seasons while the tree was growing.

Taken as a whole, these figures show clearly the wide range of variation between different varieties, whatever are the conditions of growth of the scion before cutting, or of the graft. Bough roots in nearly every case, while Tolman roots in very few cases. The relatively high per cent of Tolman in Series 3 may be looked on as a chance variation due to small numbers.

TABLE 5. — *Trees rooting in Different Years.*

	SERIES 1, 1912–13.		SERIES 2, 1913–14.		SERIES 3, 1914–15.		SERIES 4, 1915–16.		SERIES 5, 1916–17.		SERIES 6, 1917–18.		Average.
	Number grown.	Per Cent rooting.	Number grown.	Per Cent rooting.	Number grown.	Per Cent rooting.	Number grown.	Per Cent rooting.	Number grown.	Per Cent rooting.	Number grown.	Per Cent rooting.	
Baldwin,	105	16	215	53	50	48	56	39	96	23	356	22	32
Ben Davis,	112	41	147	74	62	71	49	39	138	49	119	38	51
Bough (Sweet),	144	100	202	100	90	97	–	–	77	93	39	92	98
Hubbardston,	157	11	48	11	81	19	661	23	–	–	–	–	21
Jewett,	12	35	148	21	162	21	203	14	–	–	55	18	20
Northern Spy,	149	43	216	70	68	66	132	52	–	–	187	16	58
Oldenburg,	132	42	128	48	113	46	260	21	51	39	274	4	26
Red Astrachan,	113	42	128	91	61	97	169	63	–	–	130	52	67
Rhode Island Greening,	140	26	228	58	213	31	77	31	98	21	223	11	30
Tolman,	62	0	109	6	25	56	392	6	98	0	736	1	3
Wagener,	152	40	225	58	66	80	139	32	–	–	94	13	45
Wealthy,	77	39	138	44	122	20	107	21	49	22	188	2	25
Yellow Transparent,	64	38	201	66	236	46	222	17	–	–	418	5	26
Average per cent,	–	36	–	54	–	54	–	30	–	35	–	23	–

PIECE AND SIDE-ROOT GRAFTS.

It was suggested that side-root grafts might root better than those made in the usual manner of root grafts, and this was tried out, as shown in Table 6. Considerable pains were taken to get a reasonably good fit with the side-root grafts. It required more time to make them, and they were more inconvenient to plant. The root used was about 2 to 3 inches long, and the scion projected below the union about the same distance. As shown by Table 6, side-root grafts did root considerably better than whip grafts, but this gain was more than offset by the smaller proportion of the grafts growing. Of the whip grafts, 37 per cent of the number planted made own-rooted trees, while of the side grafts only 30 per cent showed roots from the scion. Therefore this test indicates no advantage of the side-root graft over the ordinary whip graft in establishing trees on their own roots.

TABLE 6. — *Piece and Side-root Grafts.*

	PIECE ROOT.			SIDE ROOT.		
	Total Number planted.	Per Cent growing.	Per Cent rooting.	Total Number planted.	Per Cent growing.	Per Cent rooting.
Baldwin,	529	55	47	173	55	67
Ben Davis,	284	69	77	124	50	60
Bough (Sweet),	244	82	100	110	44	100
Fall Pippin,	109	77	45	48	67	61
Jonathan,	162	79	21	74	24	71
Maiden Blush,	84	67	63	22	41	100
Ontario,	43	77	44	18	28	100
Pumpkin Sweet,	60	85	27	55	53	28
Primate,	61	72	100	41	32	100
Red Astrachan,	369	69	92	88	46	90
Rhode Island Greening,	359	70	55	149	26	62
Tolman,	80	78	11	96	40	0
Tompkins King,	149	76	91	38	71	92
Wealthy,	367	73	44	111	33	45
Williams,	168	77	40	24	22	100
Average per cent,	-	74	57	-	42	72

Dwarf Apple and Pear Nurse Roots.

Attention is frequently called to the fact that if dwarf apple trees are planted deep enough for the scion to be surrounded by soil it is likely to throw out roots, and the tree intended for a dwarf becomes a standard. To test whether scions worked on dwarf stocks would throw out roots more readily than those on crab stocks, several hundred grafts were made in the usual manner in Series 2 and 3, and the results are shown in Tables 7 and 8. The standard roots were mostly Kansas grown, while the two types of Paradise stocks were imported from France. It has been shown that there are several different types of Paradise, and just which types these were was not determined further than that the English Paradise was larger and stronger growing than the French Paradise stocks.

The data in Table 7 are not full enough to permit any definite comparison. The scions grew and rooted about as well on one stock as another.

Table 8 shows that in Series 2 the trees on dwarf stocks did not give as good a stand, but rooted better than those on standard stocks. Of the former, 43 per cent of the grafts planted gave own-rooted trees, and of the latter, 41 per cent rooted from the scion. The general conclusion is that dwarf roots offer no advantage over standard roots for growing own-rooted trees.

Table 7. — *Standard and Dwarf Roots.*

	Standard.			English Paradise.			French Paradise.		
	Number planted.	Per Cent growing.	Per Cent rooting.	Number planted.	Per Cent growing.	Per Cent rooting.	Number planted.	Per Cent growing.	Per Cent rooting.
Baldwin,	257	27	63	168	18	19	–	–	–
Ben Davis,	288	22	77	130	29	63	–	–	–
Bough (Sweet),	188	32	100	172	51	95	–	–	–
Hubbardston,	–	–	–	163	25	22	105	46	16
Jewett,	211	42	25	–	–	–	160	76	30
Northern Spy,	–	–	–	101	41	53	61	64	77
Oldenburg,	316	33	48	50	20	60	179	20	36
Red Astrachan,	215	46	96	71	46	93	–	–	–
Rhode Island Greening,	258	45	53	68	9	0	187	78	20
Transcendent,	168	15	85	187	17	65	–	–	–
Wagener,	155	32	83	106	15	100	73	56	79
Wealthy,	378	34	21	138	13	11	148	45	37
Yellow Transparent,	224	67	50	279	14	43	–	–	–

TABLE 8. — *Standard and French Paradise Roots.*

	STANDARD.			FRENCH PARADISE.		
	Number planted.	Per Cent growing.	Per Cent rooting.	Number planted.	Per Cent growing.	Per Cent rooting.
Ben Davis,	284	69	77	49	39	100
Bough (Sweet),	244	82	100	37	81	100
Rhode Island Greening,	359	70	55	54	35	70
Tompkins King,	149	76	91	47	57	67
Wealthy,	367	73	44	37	57	44
Average per cent,	–	74	55	–	54	76

At the outset of this work a number of grafts on the common French pear and on sand pear roots were made in addition to those on standard apple roots and some on English Paradise. It was thought that inasmuch as the pear roots would make but a poor growth, a greater number might root from the scion. Table 9 shows the number of grafts planted and the per cent growing in July following the planting. The grafts on both sand pear and French pear gave much poorer stands than those on standard or Paradise apple roots. Many of them perished before the time of digging at the end of the second summer, so that the records of the number rooting from the scion are too few and fragmentary to be worth presenting. The indications are that on both of the pear roots more trees rooted and had a stronger root system than on apple roots, but so few grafts grew that pear roots are not desirable for propagating apple trees on their own roots.

TABLE 9. — *Trees Growing on Apple and Pear Roots.*

	STANDARD APPLE.		PARADISE APPLE.		SAND PEAR.		FRENCH PEAR.	
	Number planted.	Per Cent growing.	Number planted.	Per Cent growing.	Number planted.	Per Cent growing.	Number planted.	Per Cent growing.
Arkansas,	50	76	–	–	25	22	24	8
Baldwin,	48	69	20	80	49	33	35	61
Ben Davis,	48	69	19	63	25	68	23	48
Bough (Sweet),	40	60	13	63	9	22	17	59
Gravenstein,	54	35	–	–	20	23	–	–
McIntosh,	75	60	9	78	17	32	–	–
Hubbardston,	50	54	15	73	22	23	–	–
Northern Spy,	35	51	28	89	50	28	40	25
Oldenburg,	52	46	15	24	–	–	25	22
Red Astrachan,	56	53	15	16	50	0	37	2
Rhode Island Greening,	51	61	20	50	30	12	12	0
Roxbury Russet,	50	84	15	67	–	–	22	23
Wagener,	50	76	15	87	36	28	25	40
Wealthy,	73	37	13	77	52	2	28	3
Williams,	41	24	15	24	–	–	–	–
Yellow Transparent,	44	65	20	49	40	25	25	8

EFFECT OF BUDDING ON ROOT FORMATION.

In order to save time in getting trees on known roots the earlier series of grafts were budded usually in August after planting. Then on digging, those that had formed roots from the scion were chosen for further work, and those failing to do so were rejected. Six top or bud varieties and fourteen stock or root varieties shown in Table 10 were used. The first column of figures in the table shows the rooting from the scion of the stock varieties, and these figures may be used as a standard for comparison. The other columns show the rooting of the stock varieties when budded with the six bud varieties. The figures in this table show great variation, but, on the whole, as shown by the averages at the bottom, Baldwin and Wagener tops have induced higher percentages of rooting than non-budded trees, while McIntosh, Tolman and Yellow Transparent lowered the percentage rooting. Red Astrachan caused no change.

It is questionable how much significance can be attached to these figures. In the case of the individual lots of budded trees the numbers involved are too few to place much dependence upon. In the case of the averages the numbers are, of course, greater, and it is fair to assume that Wagener buds, and more strikingly Baldwin buds grown during the second season of growth, may have, on the whole, favored root formation from these stock varieties.

TABLE 10. — *Influence of the Bud on Root Formation.*

STOCK VARIETY.	BUD VARIETY.													
	OWN ROOTS.		BALDWIN.		MCINTOSH.		RED ASTRACHAN.		TOLMAN.		WAGENER.		YELLOW TRANSPARENT.	
	Total.	Per Cent rooting.	Total.	Per Cent rooting.	Total.	Per Cent rooting.	Total.	Per Cent rooting.	Total.	Per Cent rooting.	Total.	Per Cent rooting.	Total.	Per Cent rooting.
Baldwin,	110	49	37	38	42	31	53	25	64	30	47	72	50	38
Ben Davis,	93	70	42	74	35	74	60	48	63	40	51	57	45	62
Bough (sweet),	134	98	47	100	35	100	38	100	39	100	46	100	36	100
Hubbardston,	125	22	83	26	39	10	59	29	62	18	66	15	61	15
Jewett,	240	22	60	13	42	21	71	34	49	20	53	19	54	26
Northern Spy,	139	63	67	52	58	43	93	51	35	43	60	75	46	78
Oldenburg,	276	34	91	20	52	35	49	33	55	35	55	55	44	36
Red Astrachan,	195	74	69	71	67	64	65	89	64	75	58	67	54	57
Rhode Island Greening,	219	42	68	46	60	25	63	32	61	31	63	33	85	32
Tolman,	269	8	91	11	38	5	45	7	36	6	60	7	67	6
Transcendent,	273	47	18	72	43	51	19	58	57	44	20	50	10	20
Wagener,	203	53	54	59	48	44	70	33	46	43	62	70	57	37
Wealthy,	233	25	40	62	45	38	55	45	41	33	43	46	43	37
Yellow Transparent,	352	34	50	66	64	34	51	65	55	58	56	57	85	39
Average per cent,	–	46	–	61	–	41	–	46	–	41	–	52	–	42

Grafting on Known Roots.

Once trees are established on roots of known varieties it would seem a desirable process to dig such trees and cut off the greater part of the root system and replant them, that they may re-establish themselves on a renewed root system. Then the roots cut off may be used for grafting in the ordinary manner with scions of the same variety as the root. By this method own-rooted trees should be secured without resorting to the seedling nurse root, the subsequent removal of which is a severe check to the young tree, especially with those varieties that do not root freely.

This method was tried out in 1915–16. Trees were dug in the fall and all roots suitable for whip grafting removed and the trees reset, the tops being severely cut back. All recovered and in time became vigorous trees. The roots were stored in moist sand and grafted in February and set in April. For some reason they failed to make a good stand, and those that did grow made less growth than adjoining trees grafted in a similar manner on seedling roots. The number of grafts planted, and the percentages growing in July after planting and also in July a year later, are shown in Table 11. Seedling roots used in grafting are commonly one year old, while some of these roots were three or four years old, and this may have been responsible for the poor stand. The very fine sand in which the roots were stored was rather wet and compact, and this may have interfered with respiration and resulted in injury to the roots. It seems hardly reasonable to suppose that such poor results must necessarily follow grafting on the roots of known varieties.

Table 11. — *Grafts on Known Roots.*

	Number planted.	Per Cent growing.	
		July, 1916.	July, 1917.
Ben Davis,	56	39	23
Bough,	94	13	7
Northern Spy,	6	33	17
Red Astrachan,	144	14	6
Wagener,	65	12	5
Wealthy,	69	4	1

HISTOLOGY OF THE TWIG IN RELATION TO ROOT FORMATION.[1]

Roots on the scion usually arise near a bud, either singly or in twos or threes. No case has been observed when roots arose at a node opposite the bud. Roots may also arise from the internode, but generally within a half inch of the node. Generally they arise above rather than below the bud. The first indication of the root is the falling away of the axillary bud and the appearance of a swelling with two or three brownish white areas, — the growing points of the young roots.

Free rooting varieties develop roots early in the season. An examination of Bough grafts in July showed that they were rooting freely. At the same time Red Astrachan, Ben Davis and Tompkins King showed incipient root formation in a few cases, while poor rooting varieties showed no signs of roots. An examination about the middle of October showed progress in all these varieties, but the poorer rooting varieties showed hardly a tree with roots from the scion. Always, on digging, the poor rooting varieties have small roots (see Fig. 3) which have evidently formed the second season of growth.

If we examine a cross section of a one-year-old twig we find between the bark and wood the cambium, consisting of a layer of eight to fourteen very small, thin-walled rectangular cells. Measurements of the thickness of the cambium layer were made and the number of cells noted on a number of the varieties used. Measurements of the thickness of the bark were also made.

In choosing material, fresh twigs of the previous season's growth, from both bearing and nursery trees, were selected, and cross sections made usually at the fifth node back from the terminal bud. In the case of some immature tips it was necessary to go further back to secure a plump, mature bud. Sections were made with a sliding microtome and placed at once in 30 per cent alcohol for ten minutes. Then the alcohol was poured off and the sections stained for three to five minutes with Delafield's Hematoxylin, washed, mounted on the slide and measured at once. Measurements of the bark were to the wood, and included the cambium layer. They were made at a point one-fourth around the circumference of the twig from the bud when possible, and in all cases care was taken to avoid the thickened bark near the bud. The limits of the bark as thus defined were clear, but more difficulty was experienced in measuring the cambium layer because of a less clear differentiation between it and the phloëm. Often there are two or three cells that have no distinctive features of either cambium or phloëm. In order to establish a limit the phloëm was considered as starting with the first cell, in which the cells were markedly larger and more rounding, with walls less deeply stained. In this way a fairly satisfactory criterion was established. (See Plates III and IV.) Four to thirteen twigs of each variety were examined and five to ten measurements and counts of cambium cells made on each twig. No differences were detected between shoots from nursery trees and from bearing trees. Table 12 gives the results of these measurements.

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[1] This discussion is based on work by Robt. P. Armstrong, graduate assistant, to whom the credit for it is due.

TABLE 12. — *Thickness of the Bark and Cambium.*

	Per Cent rooting.	Thickness of Bark in Millimeters.	Thickness of Cambium in Microns.	Number of Cambium Cells.	Range of Number of Cambium Cells.
Bough (Sweet),	98	.513	80.0	10	9–11
Primate,	92	.628	86.1	10	9–10
Red Astrachan,	67	.633	80.5	10	9–13
Tompkins King,	62	.613	80.9	–	–
McIntosh,	74	.525	78.0	9	9–10
Northern Spy,	58	.665	75.0	8	8–10
Baldwin,	32	.611	56.0	6	8–9
Yellow Transparent,	26	.571	69.8	9	–9
Oldenburg,	25	.743	75.0	9	8–9
Jewett,	20	.689	67.2	9	–9
Tolman,	3	.592	58.0	7	7–8

It appears from this table that there is a difference in the thickness and number of cells in the cambium layer of the varieties examined, and that this is correlated with the ability of the variety to form roots from the scion. The only marked exception shown in the table is the Baldwin, which, having the fewest cells and the thinnest cambium layer of all, roots more freely than four of the other varieties studied. Further study of this question, including other varieties and extending through the growing season, should prove definitely whether we have here a significant reason for the variation in root formation among different varieties.

DISCUSSION OF THE RESULTS.

As a major result of the work here reported two facts are brought out: (1) varieties differ greatly in their readiness to form roots from the scion when propagated by the nurse-root method; (2) there is also great variation within the variety in the number that form roots from the scion.

Taking up first the varietal differences we find that a few varieties root in all, or nearly all, cases, while only one variety of *Pyrus malus* — Bethel — has failed entirely to yield trees rooted from the scion. Inasmuch as this variety was grown in rather small numbers and under conditions where other varieties gave low percentages of rooting trees, it is probable that Bethel would, under more favorable conditions, give at least a low percentage of rooted trees. Considering the number of varieties tested it seems safe to say that any variety of the common apple may be propagated on its own roots by the nurse-root method.

There are fourteen varieties that have been propagated in considerable numbers in successive years and under different conditions, so that we may feel fairly certain that the percentage rooting is fairly representative for these varieties under the general conditions in which they have been grown. Arranged in order of percentage rooting they are as follows: —

Bough (Sweet),	98	Rhode Island Greening,	30
Red Astrachan,	67	Oldenburg,	26
Northern Spy,	58	Yellow Transparent,	26
Ben Davis,	51	Wealthy,	25
Wagener,	45	Hubbardston,	21
Transcendent,	45	Jewett,	20
Baldwin,	32	Tolman,	3

Coming now to the question of why certain of these varieties root better than others we find a rather difficult problem. We have made few investigations aimed directly at this question, but some discussions may be ventured.

The property of rooting is not directly correlated with vigor. Tolman is fully as strong growing a variety in the nursery as Bough. Furthermore, observations made on digging the trees fail to discover any noticeable correlation between vigor and rooting. It has seemed to the writer that a small, weak tree was as likely to be rooted from the scion as a strong one.

Some varieties branch more freely than others. During the season of 1916 a block of yearling whips branched quite freely from the newly formed axillary buds. Notes taken at the time are as follows: No branches, Northern Spy; few, Baldwin, Bough, Oldenburg, Tolman; all, Transcendent (Crab). This gives no indication of any correlation between rooting from the scion and branch growth from axillary buds. A more reasonable expectation might be for a correlation between root formation and branching from adventitious buds on the stem. No exact record of branching from adventitious buds is available, but limited general observation of the behavior of budded trees leads the writer to believe that such a correlation may exist, and that Bough and other free rooting varieties do send out shoots from adventitious buds more freely than Tolman and other varieties that root only sparingly. Further and more definite records may prove or disprove this belief.

The relation of callus formation in cuttings has been referred to. (See page 75, Fig. 1.) Unfortunately no full notes of callus formation on the cuttings set was kept, but it is suggestive to point out that Yellow

Transparent, which uniformly gave as large a callus as any variety, did not root as well as Wagener, which never gave any sign of callus formation.

Neither can we discover any relationship between rooting from the scion and season of maturity, either of fruit or wood, nor in size of leaves or density of foliage.

Many woody plants are propagated from cuttings, and in general it is those with soft wood that grow most readily. There is considerable variation in hardness of wood among different varieties of apples, and we may inquire if those with softer wood are the ones that root most readily from the scion. No extended investigation of this question has been made at this station. Beach and Allen [1] made extensive tests of the hardness of wood of different varieties. They found considerable difference within the variety, and a clear comparison of their results with rooting ability, as shown by their investigation, is difficult, but a general survey of their results leads to a belief that there is a general correlation. It is, however, subject to exceptions. Beach and Allen came to the conclusion that there was a correlation between hardness of wood and resistance to winter cold, and here again there seems to be a rather loose correlation with rooting ability. Oldenburg and Wealthy are very hardy and root poorly, and Bough is tender and roots well. But Ben Davis is quite hardy and roots comparatively well, and Hubbardston and Tolman are less hardy than Wealthy and do not root so well.

Wide variations in the rooting ability of different lots of the same variety are evident. Some of these are clearly seasonal. Such differences may be due to climatic conditions, to soil conditions, — for the soils used in different years are not all alike, — or they may be due to difference in the scions used. Any such difference would most likely trace back to the growing conditions the previous season as affecting stored food and possibly structure. Slight differences in cultural treatment may have had an effect. Varying rainfall may have had an influence. It is impossible from the evidence at hand to determine which of these possible factors have had an influence and to what extent.

The general low percentages of Series 6 (Table 5) are striking, and the writer feels that they are due largely to poorly drained soil which prevailed over a considerable portion of the plot. While no direct comparisons are possible, careful observation indicated that rooting was better on the drier portions of the plot. A part of the plot on which Series 4 was grown was poorly drained, and may account for the rather low average of this series.

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[1] Ia. Expt. Station Res. Bul. 21 (1915).

SUMMARY.

1. Stem cuttings of the common apple grow only rarely; in the trials here reported none succeeded, though callus formation in some varieties was good.

2. Root cuttings grew well, especially when young roots were used, though growth was slow the first season.

3. Limited tests indicated that most varieties may be readily propagated by mound layers.

4. The best means of establishing trees on known roots is by the nurse-root method. The scion is whip-grafted on a short piece of root and planted deeply; at the end of one or two seasons' growth the tree is dug, the seedling root removed and the tree replanted. Neither dwarf apple nor pear roots are of value as nurse roots.

5. Varieties vary greatly in the readiness with which they send out roots from the scion, the proportion varying from none to practically all with different varieties.

6. There is also great variation within the variety in the numbers rooting from the scion.

7. Varietal differences may be loosely correlated with density of the wood, the softer the wood the higher the proportion rooting from the scion.

8. A fertile, well-drained, sandy loam probably offers the best conditions for securing a high percentage of rooting trees.

9. Once trees are established on known roots they may be propagated by root cuttings or by root grafting on known roots.

10. There seems to be a relation between the varietal ability to produce roots from the scion and the thickness of the cambium layer at the dormant season.

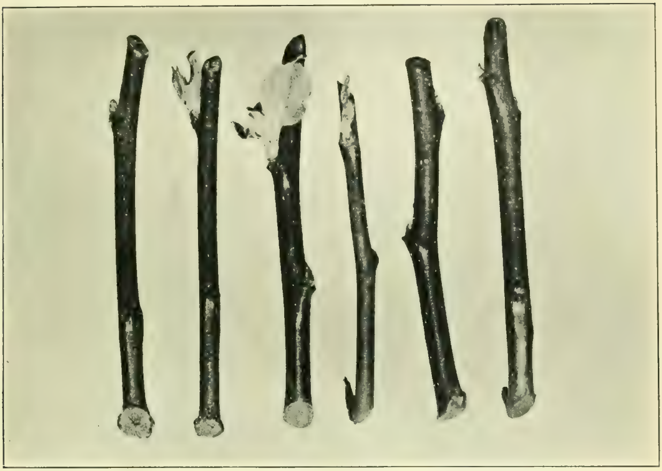

FIG. 1. — Green wood apple cuttings, showing callus formation. From left to right, Yellow Transparent, Fall Pippin, Red Astrachan, Bough, Ben Davis, Wagener.

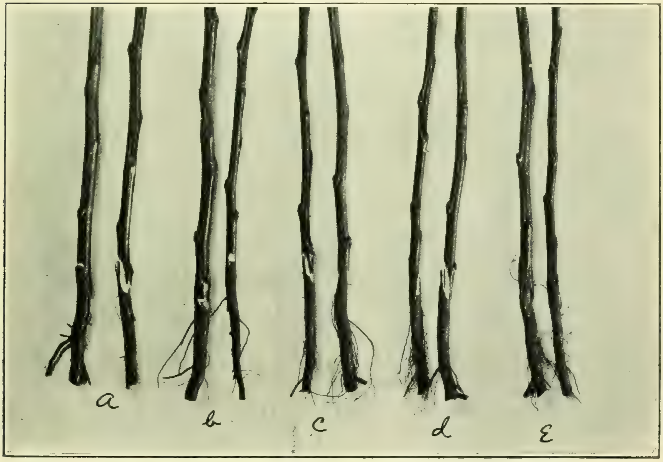

FIG. 2. — Matching cambium in root grafts: (*a*) one side only; (*b*) both sides only; (*c*) top only; (*d*) bottom only; (*e*) perfectly matched.

PLATE II.

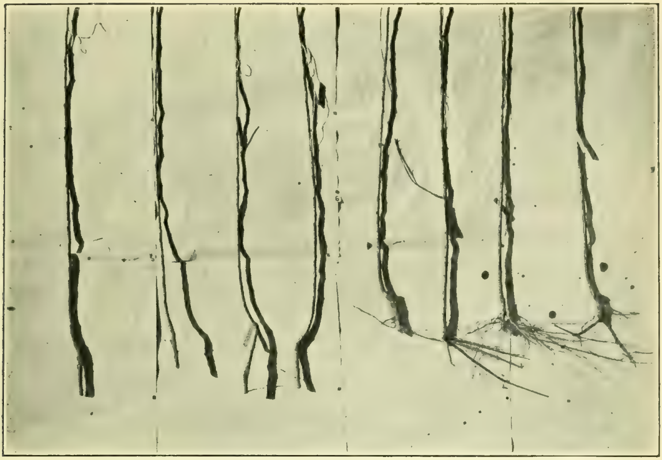

FIG. 3. — Trees rooted from the scion after cutting off seedling nurse root; two-year-old trees cut back in spring of second year. Tolman at left, Bough at right, showing stronger roots of the latter.

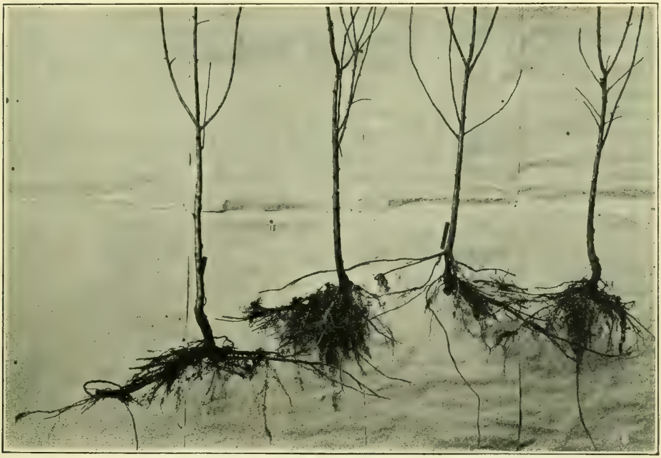

FIG. 4. — Own-rooted Red Astrachan two years after cutting off seedling root.

PLATE III.

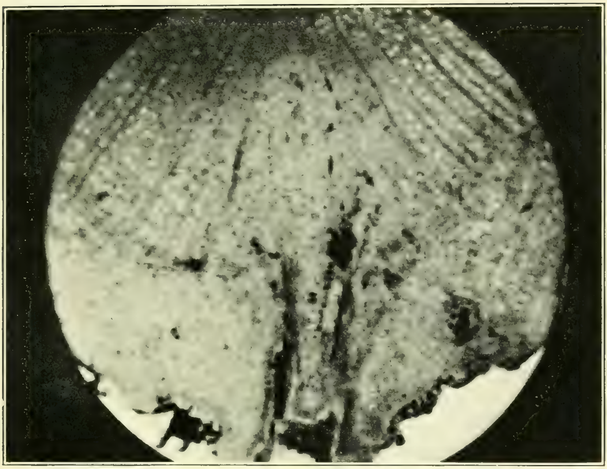

Fig. 5. — Section of Bough scion, showing origin of a young root.

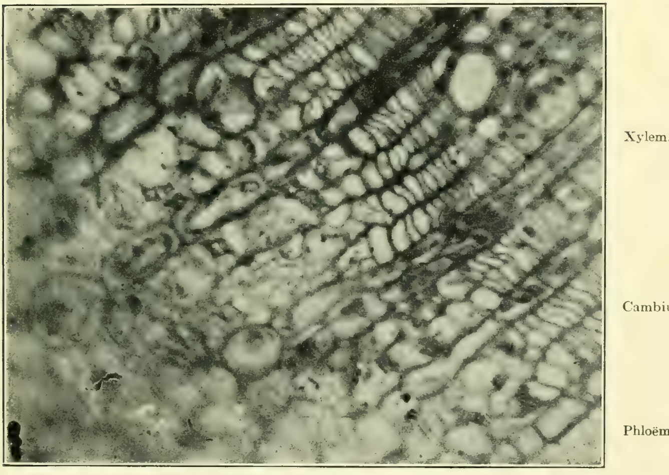
Xylem.
Cambi
Phloëm

Fig. 6. — Section of Bough, showing xylem, cambium and phloëm. The cambium layer has nine or ten cells.

PLATE IV.

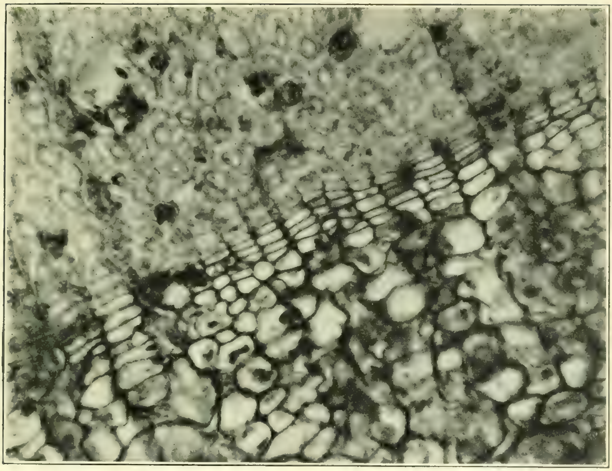
Xylem.
Cambium.
Phloëm.

FIG. 7. — Section of Baldwin, showing the thin cambium layer, averaging about five cells.

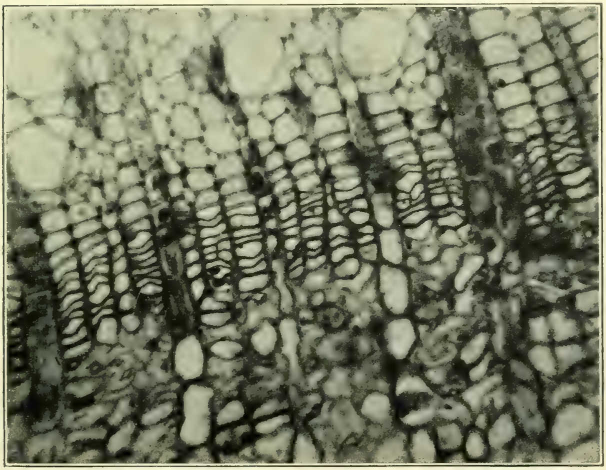
Xylem.
Cambium.
Phloëm.

FIG. 8. — Section of Tolman, showing cambium layer, averaging about eight cells.